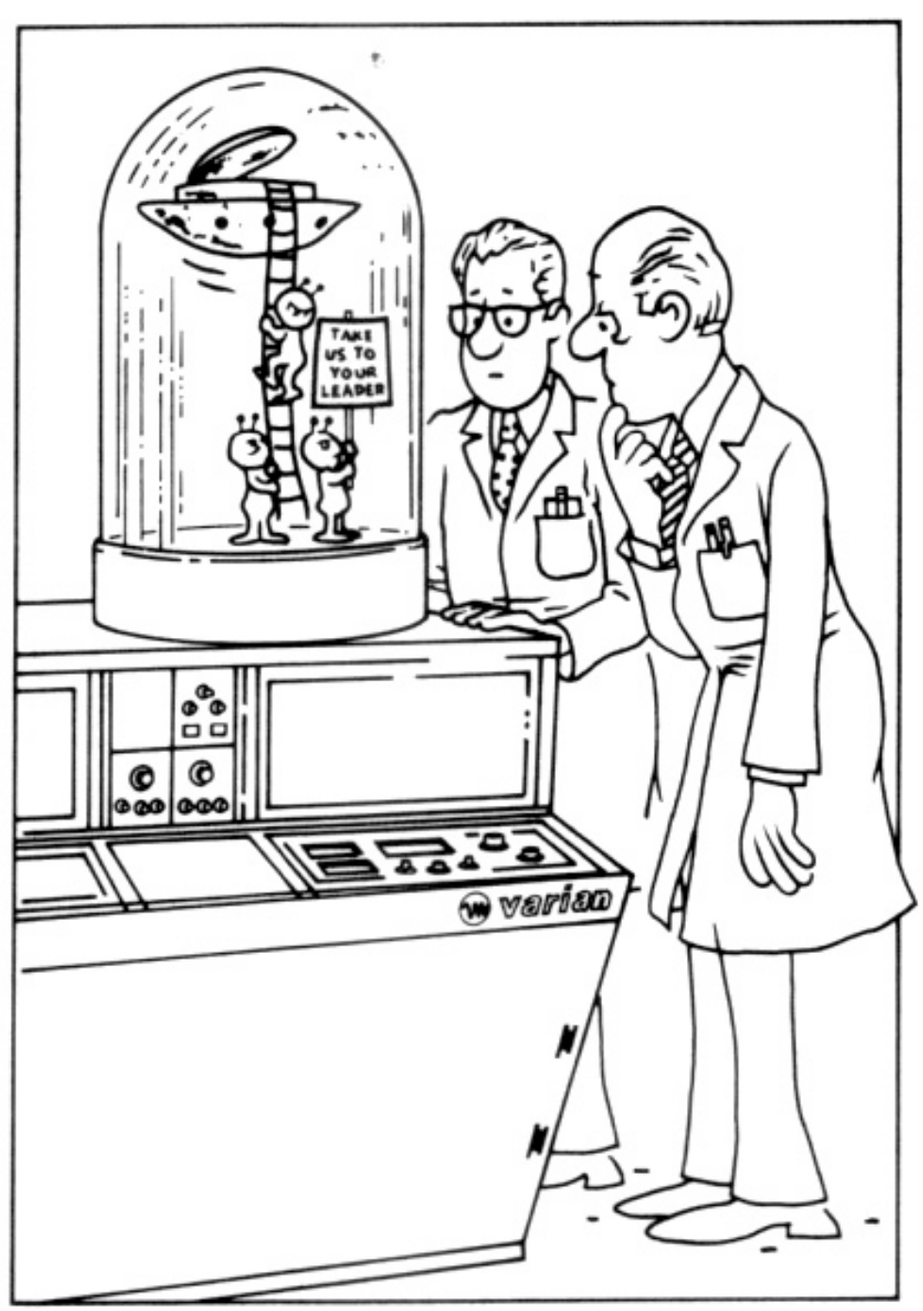
Physics 590B

Vacuum generation and monitoring



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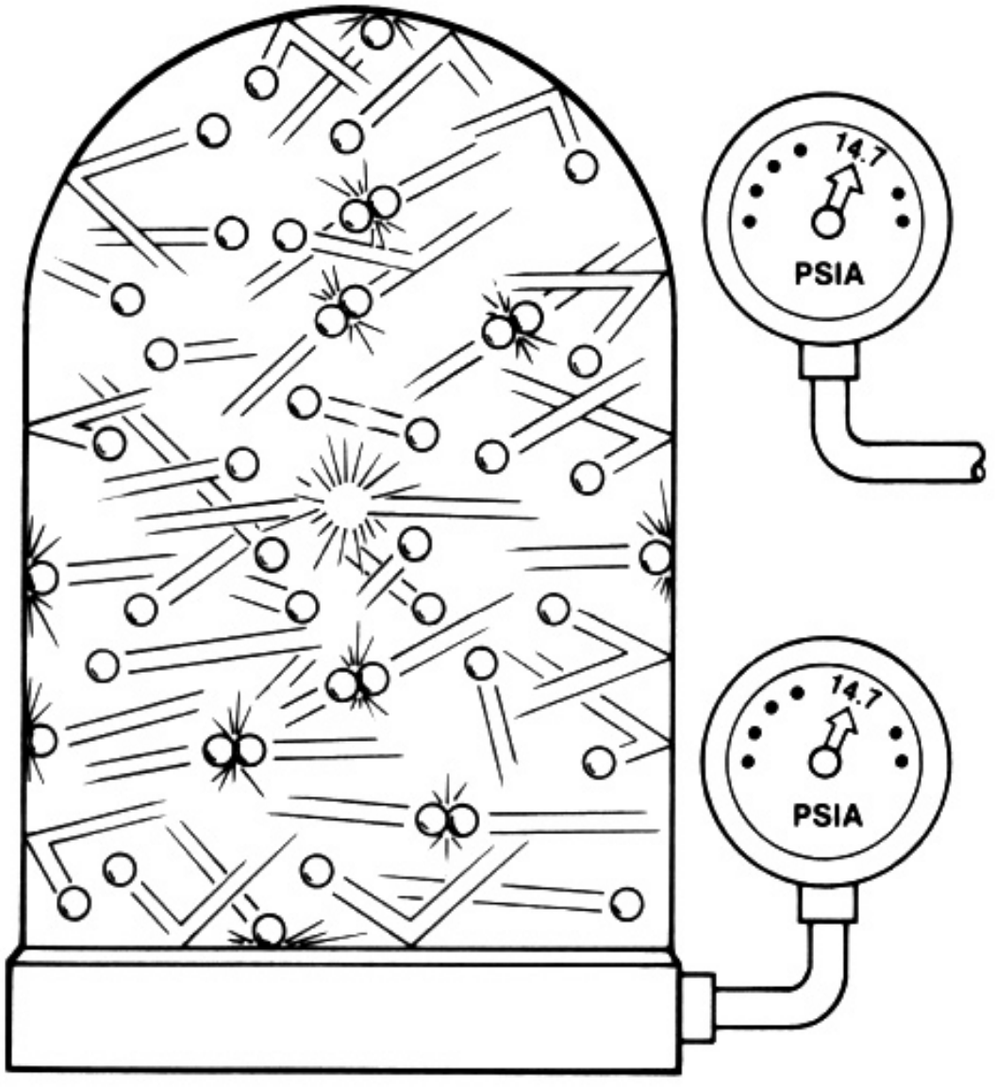
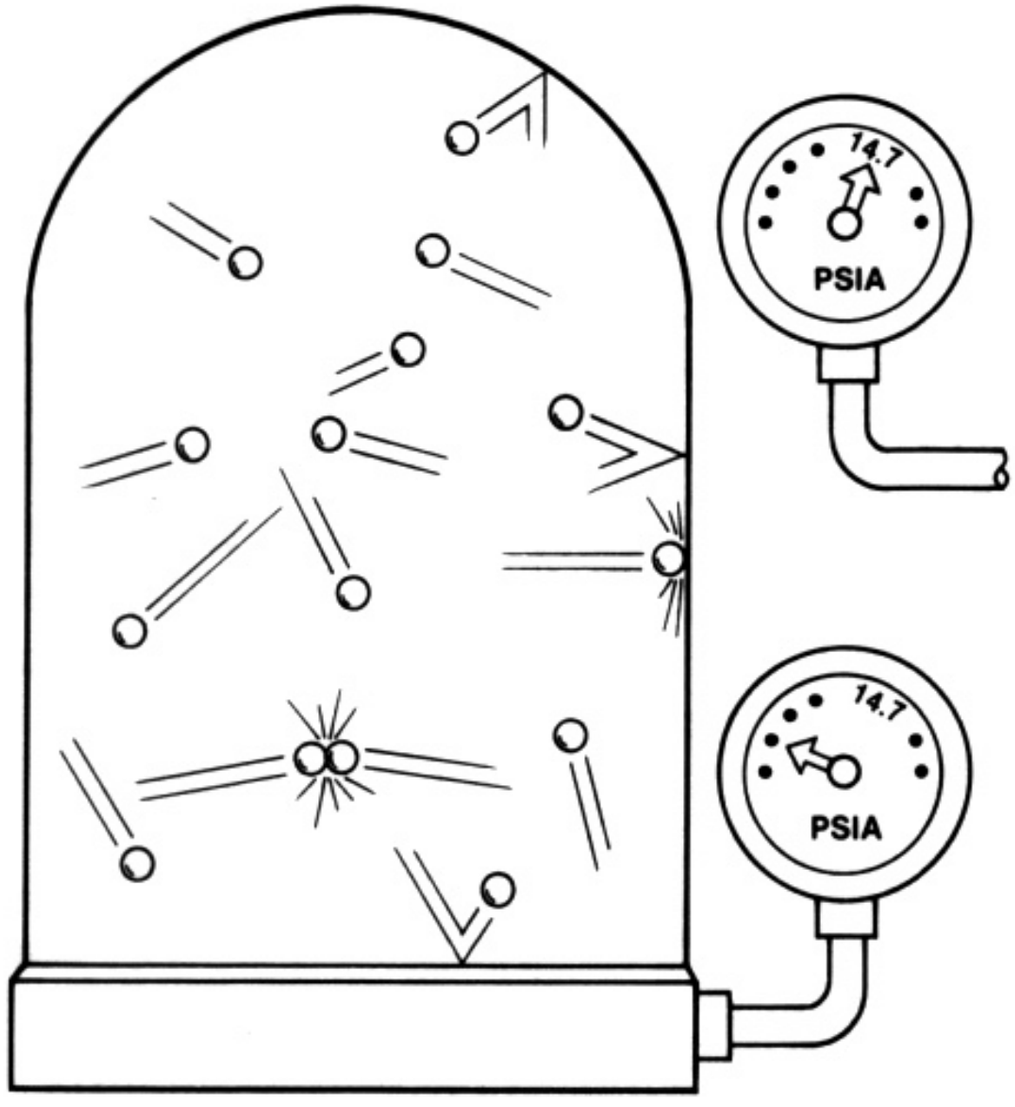
No matter how hard you pump - you cannot remove all gas molecules...

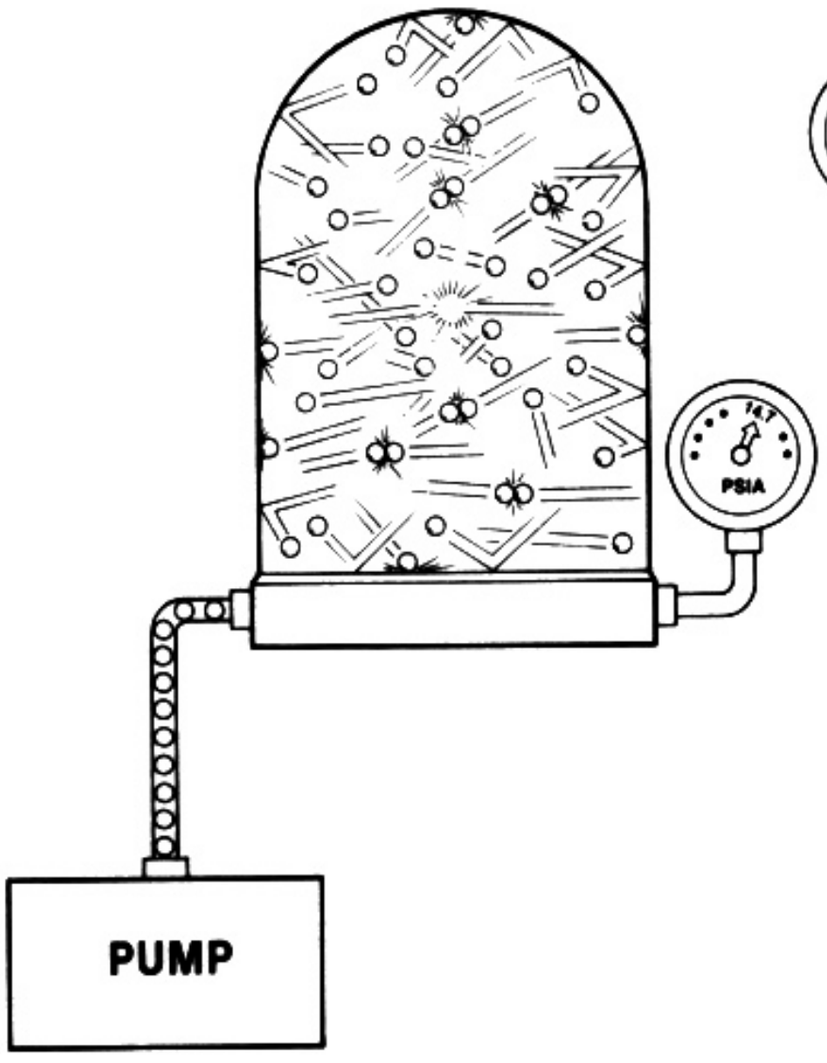




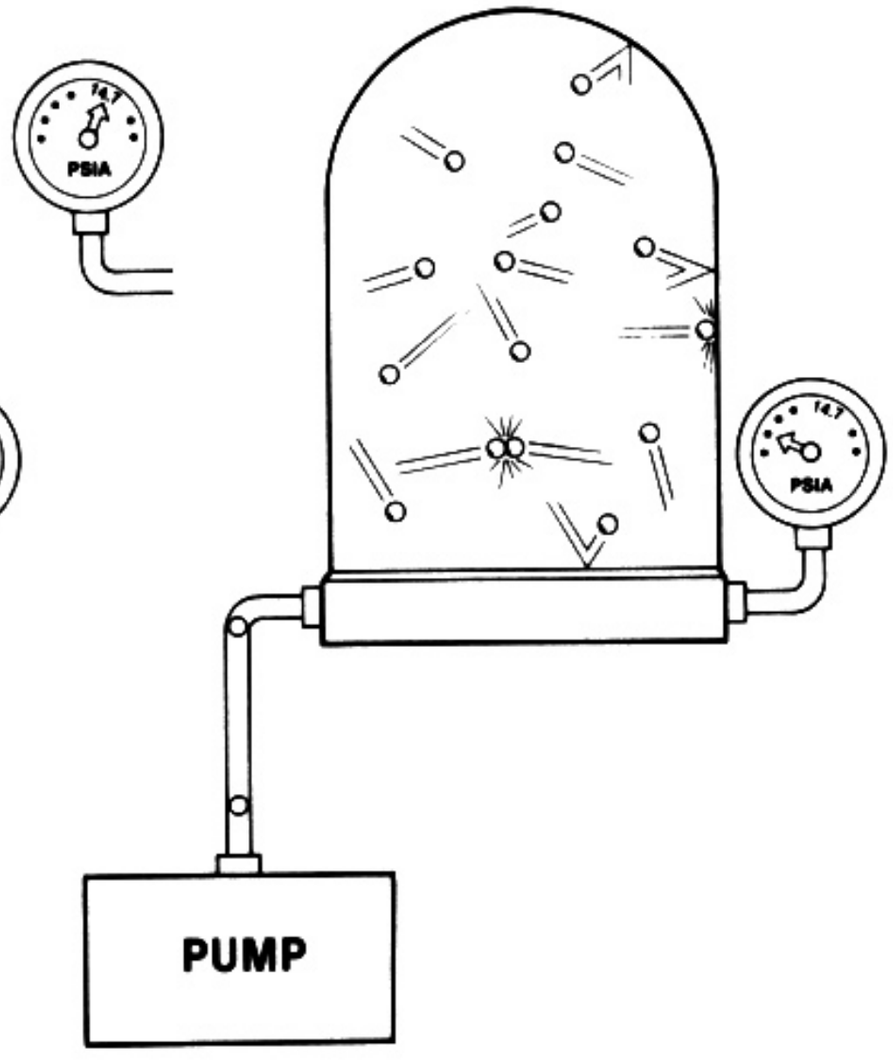
MOLECULAR DENSITY AND MEAN FREE PATH

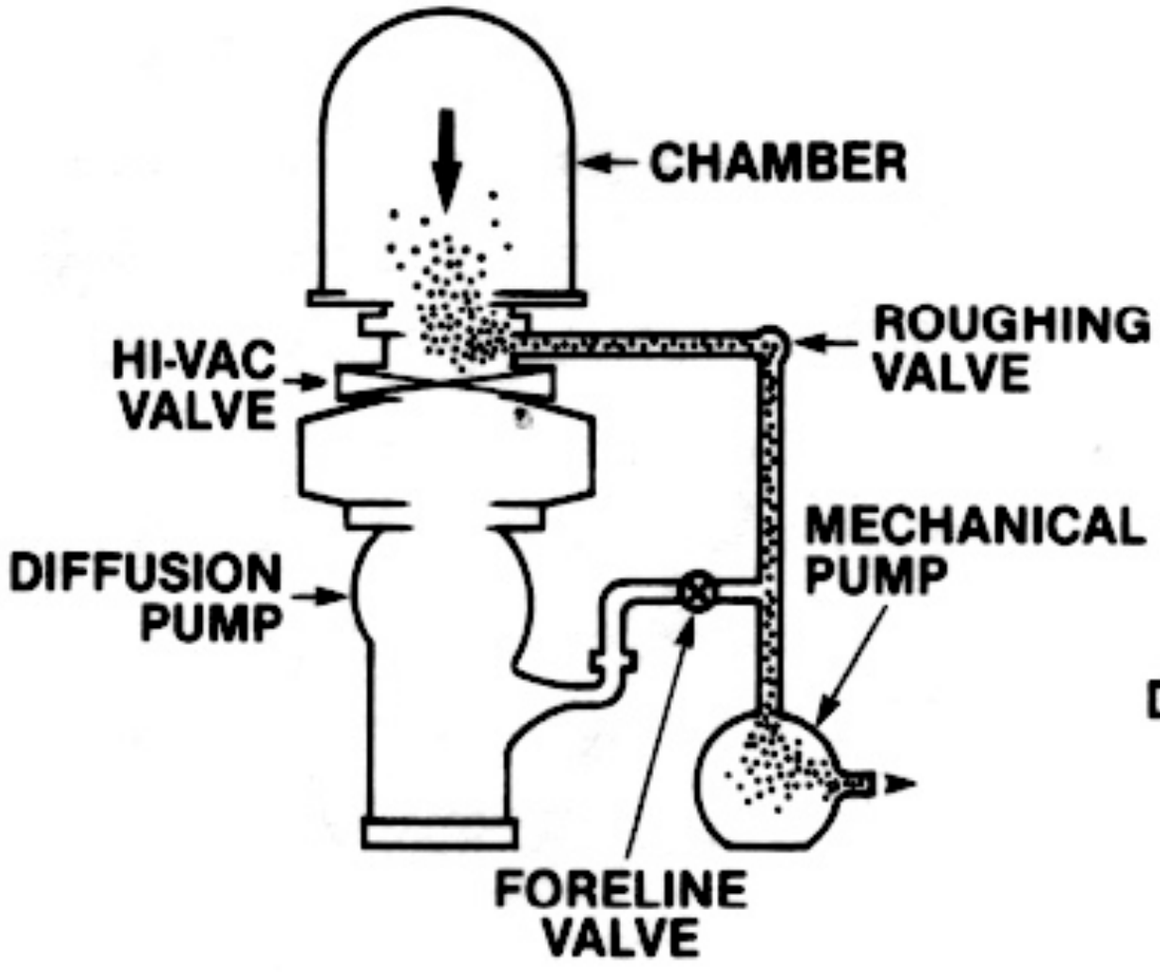
	7.6 × 10^2 Torr (atm)	1 × 10^{-3} Torr	1 × 10^{-9} Torr
# mol/cm^3	3 × 10^{19} (30 million trillion)	4 × 10^{13} (40 trillion)	4 × 10^7 (40 million)
MFP	2 × 10^{-6} in.	2 in.	30 mi

VISCOUS FLOW CONDITIONS

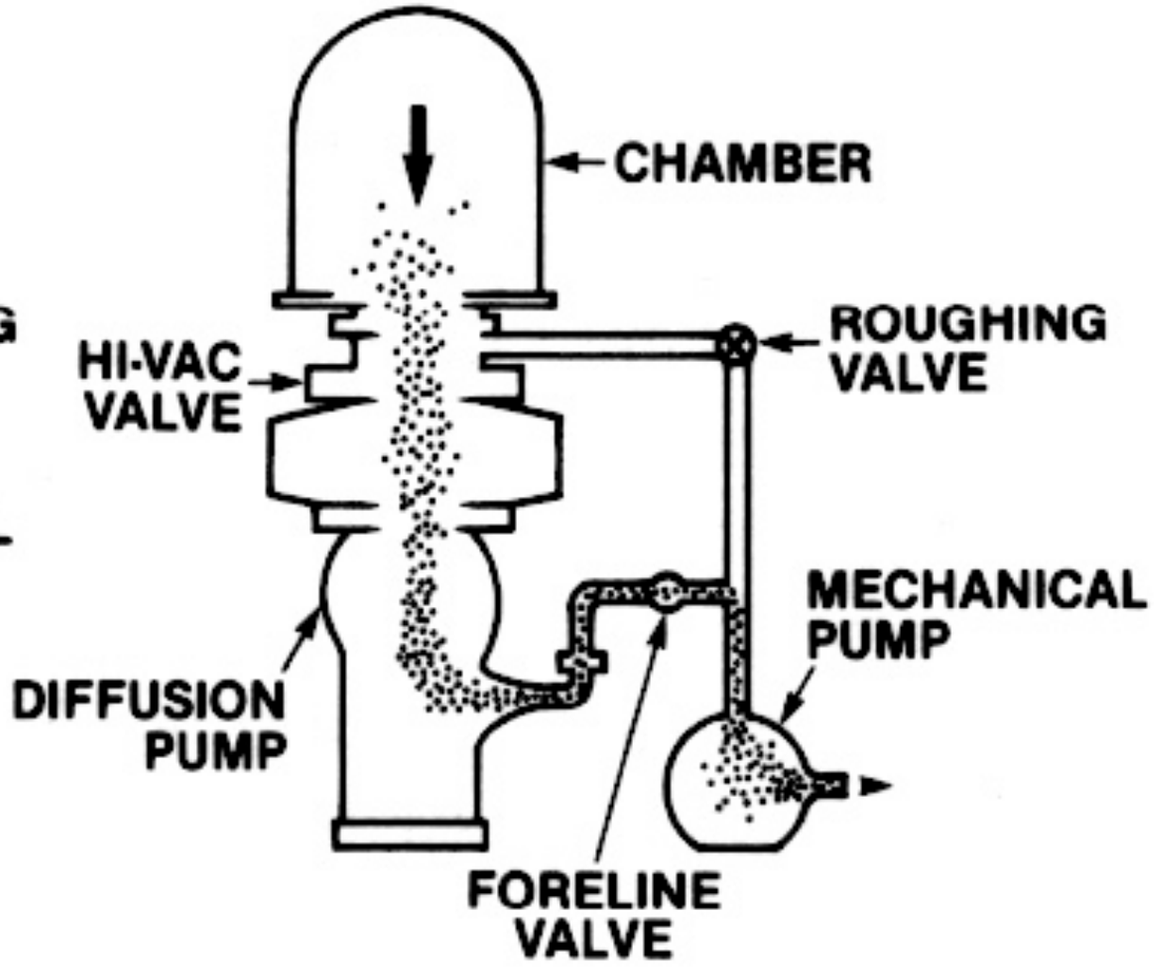


MOLECULAR FLOW CONDITIONS

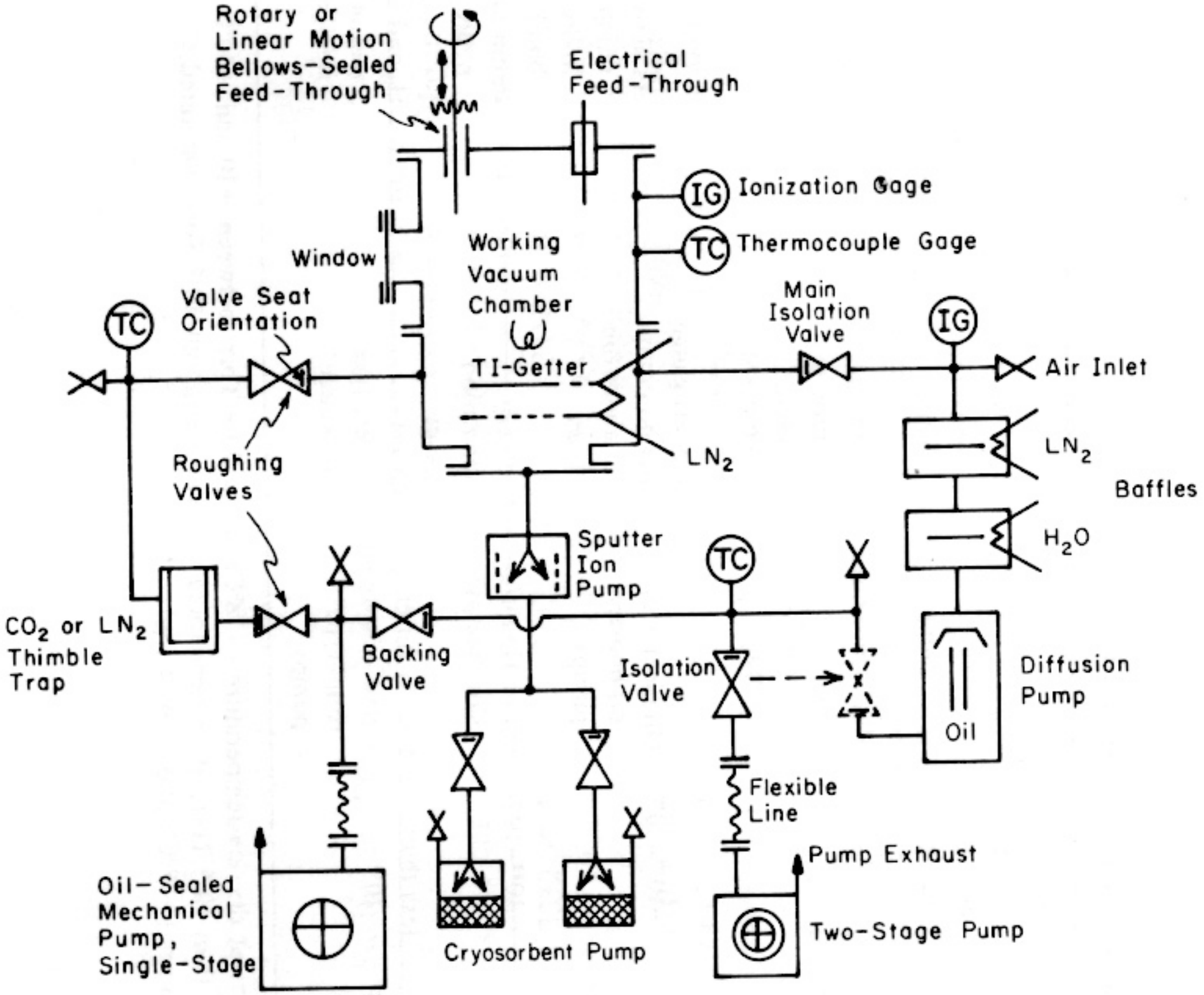




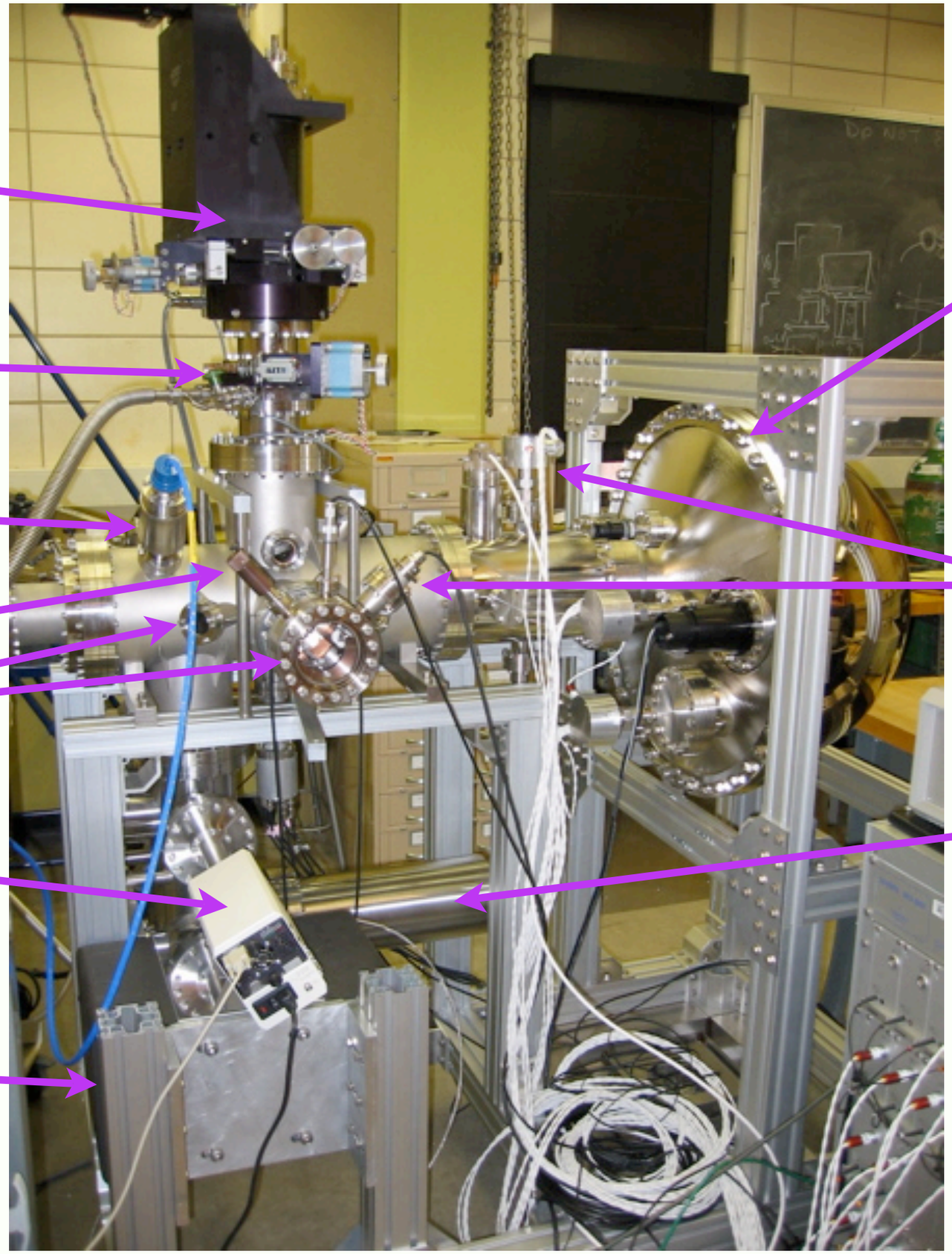
ROUGHING



FOREPUMPING



Typical UHV system



XYZ manipulator

Rotary seal

Ion gauge

Rotary feedthru

Viewports

RGA
(residual gas analyzer)

Ion pump

Really big UHV flange

Electrical feedthru's

TSP
(Titanium sublimation pump)

Chambers

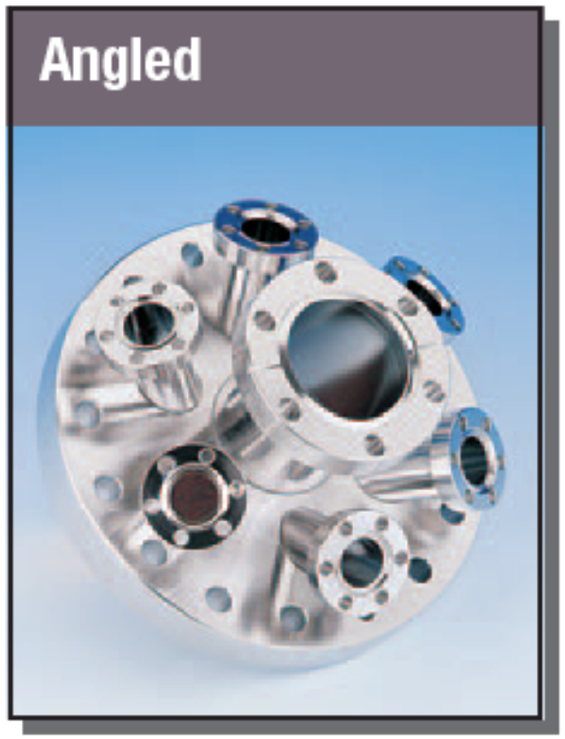
Stainless steel 304, 316:
easy to machine/weld
but transparent to H2
$p>10^{-11}$ Tr

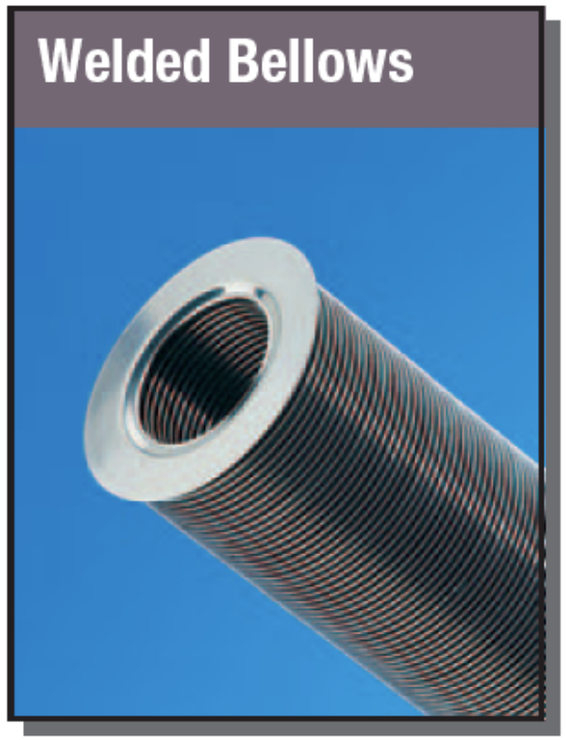
Aluminum:
fragile, expensive to make
but resistant to H2
$p<10^{-14}$ Tr

Components

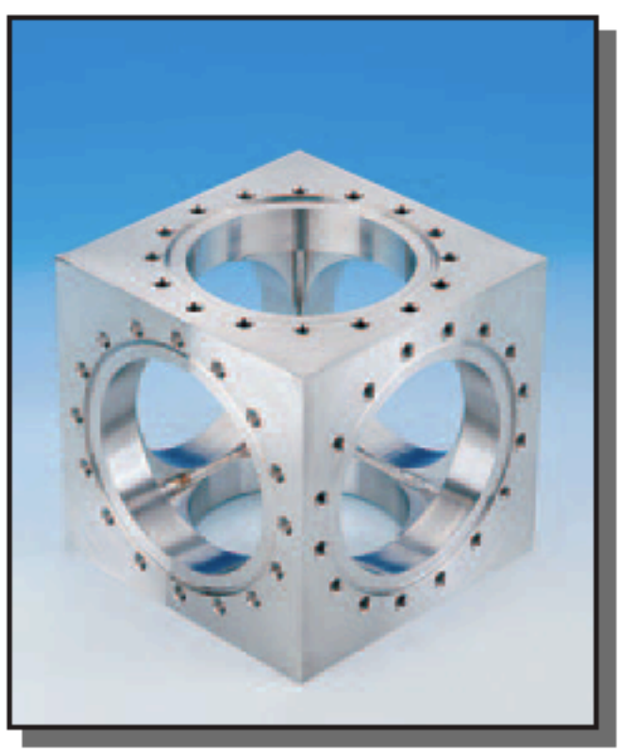
90º Del-Seal CF Elbows page 66

Del-Seal CF Reducing Cross page 71



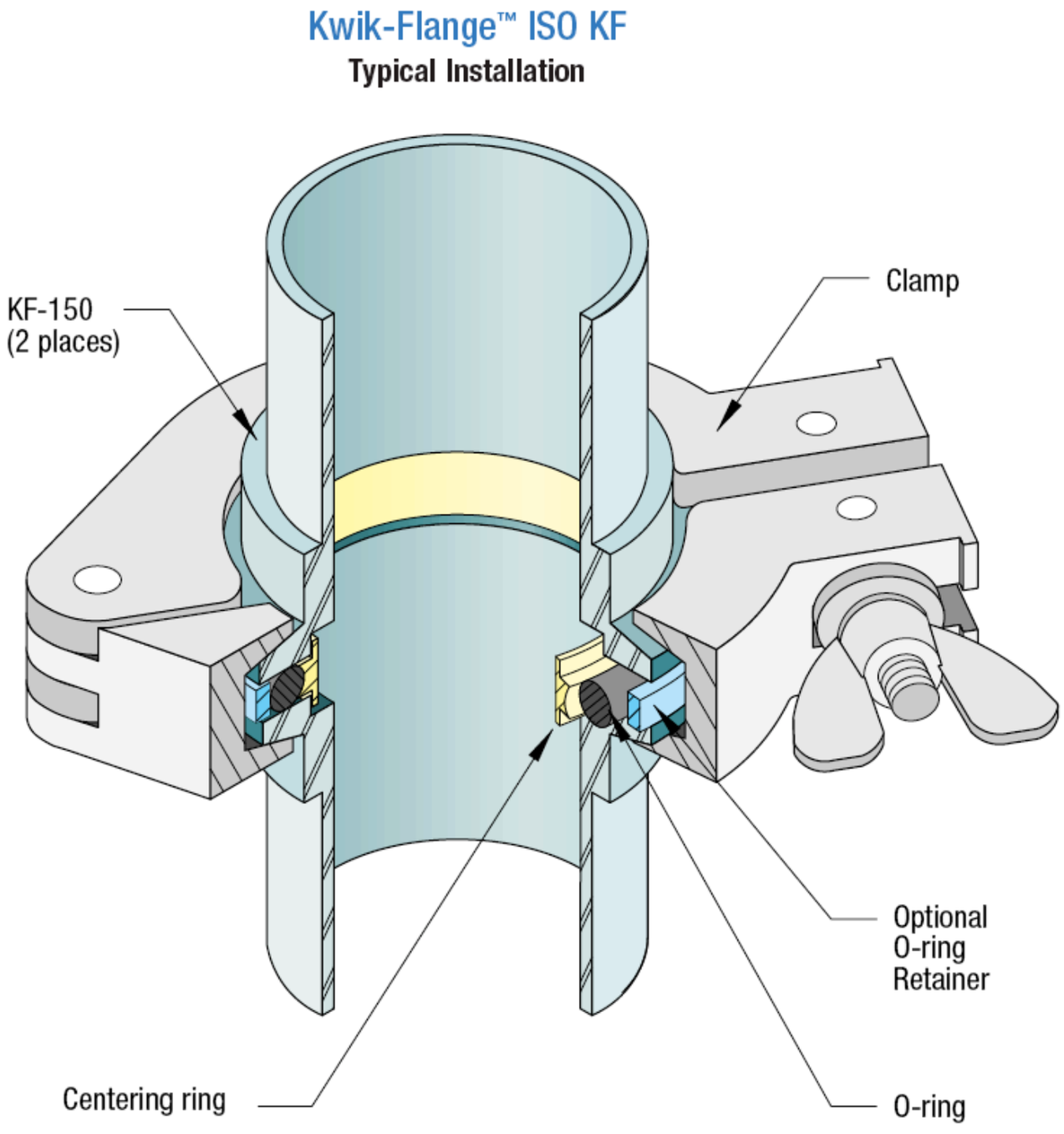


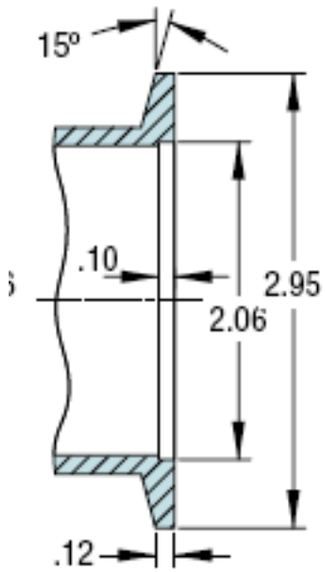
Del-Seal CF 5-Way Cross page 72

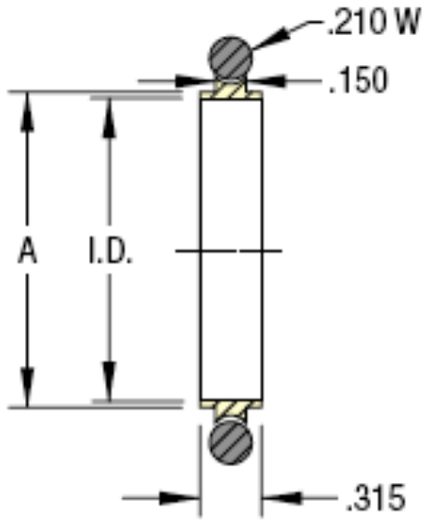


Del-Seal CF 6-Way Cube page 73

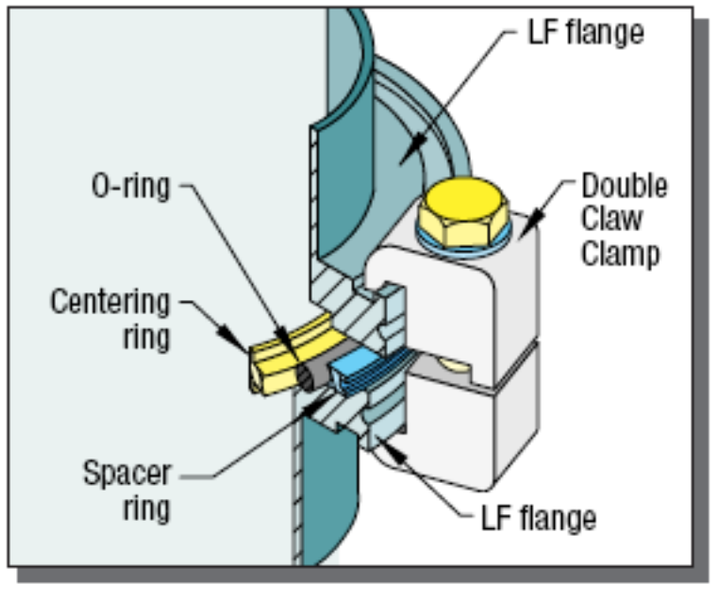
Kwik flange ISO KF

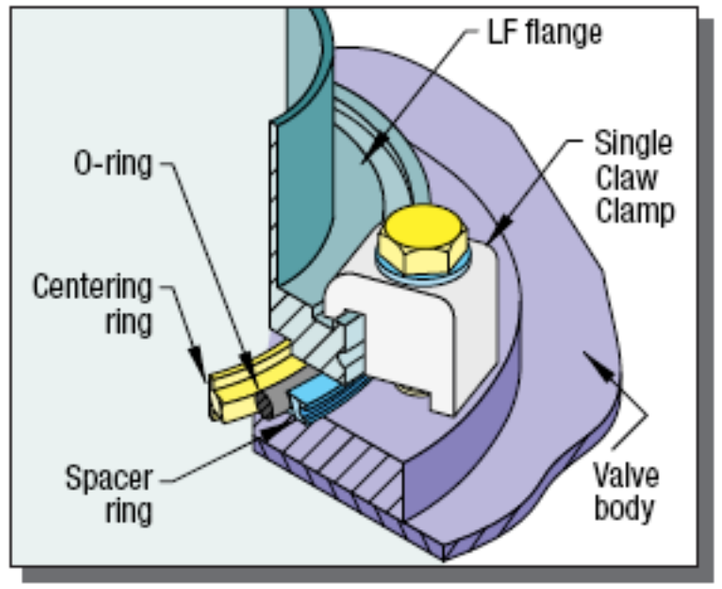


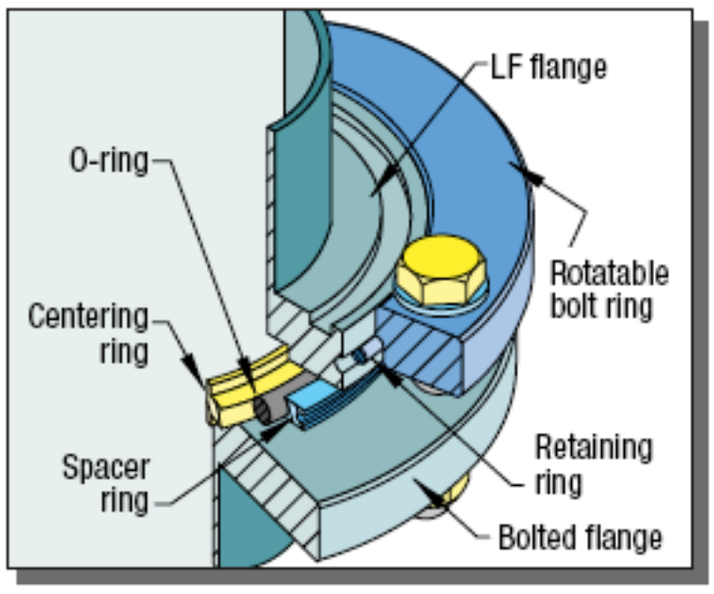




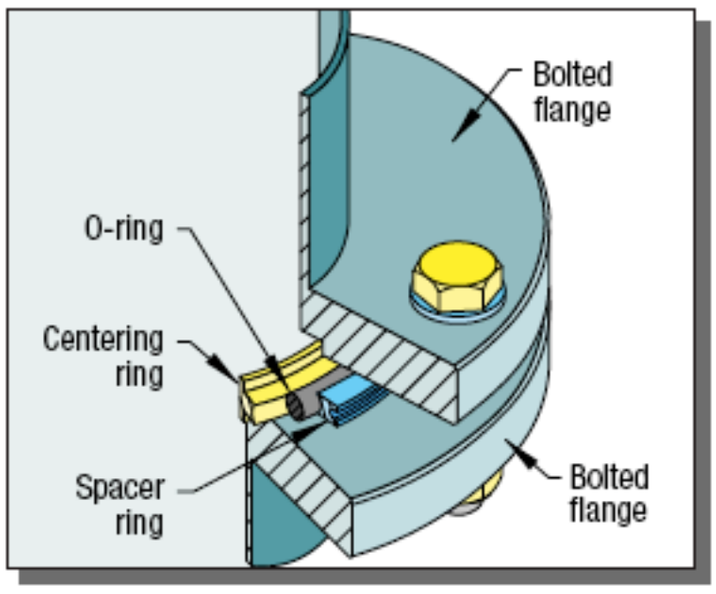
Large flange ISO KF



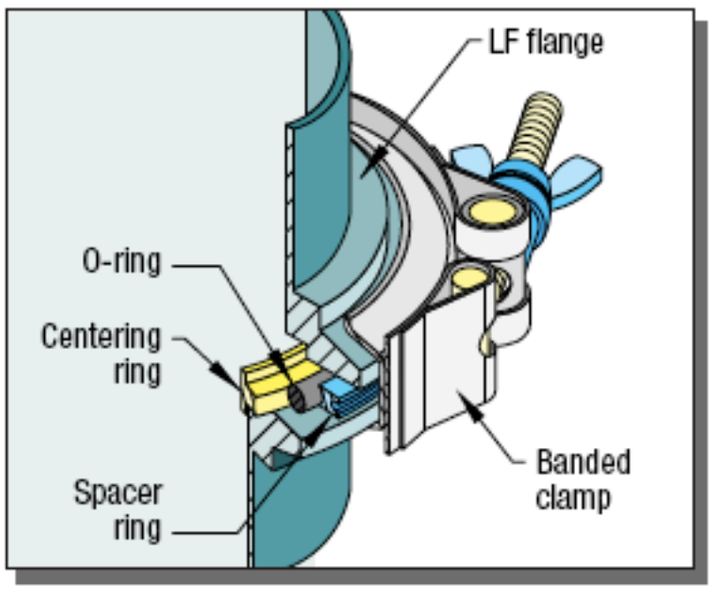




Bolted Rotatable Assembly

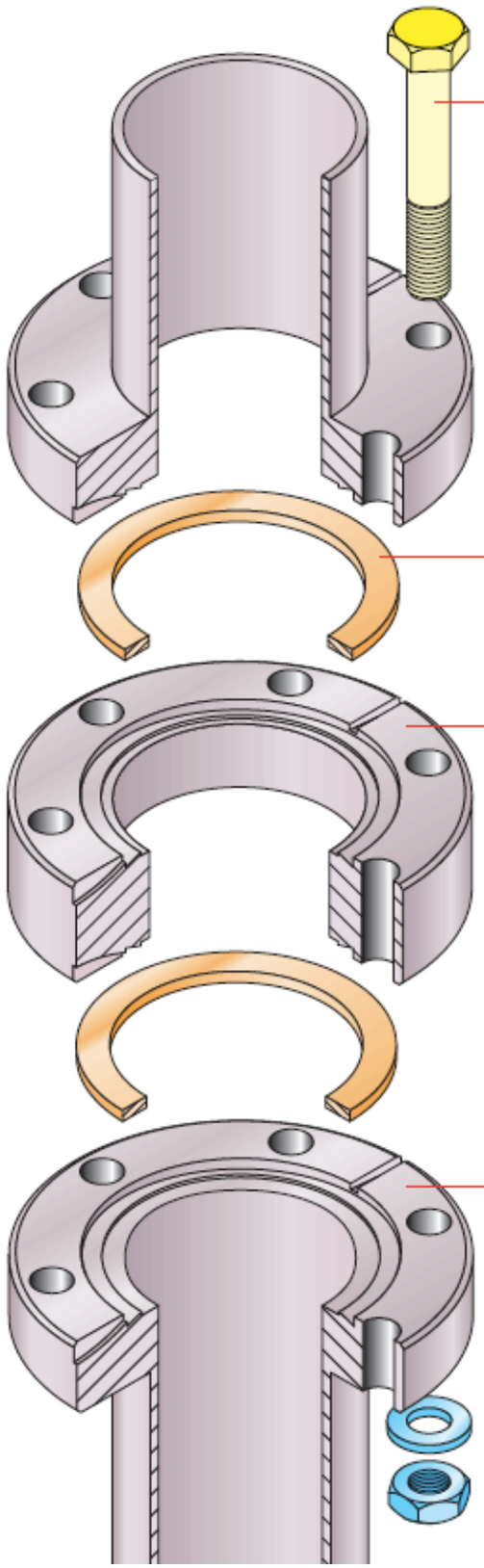


Bolted Nonrotatable Assembly



Band clamp Assembly

Conflat flange (CFF/Del Seal)



Double sided flange bolts

Extra length required to pass through three flanges

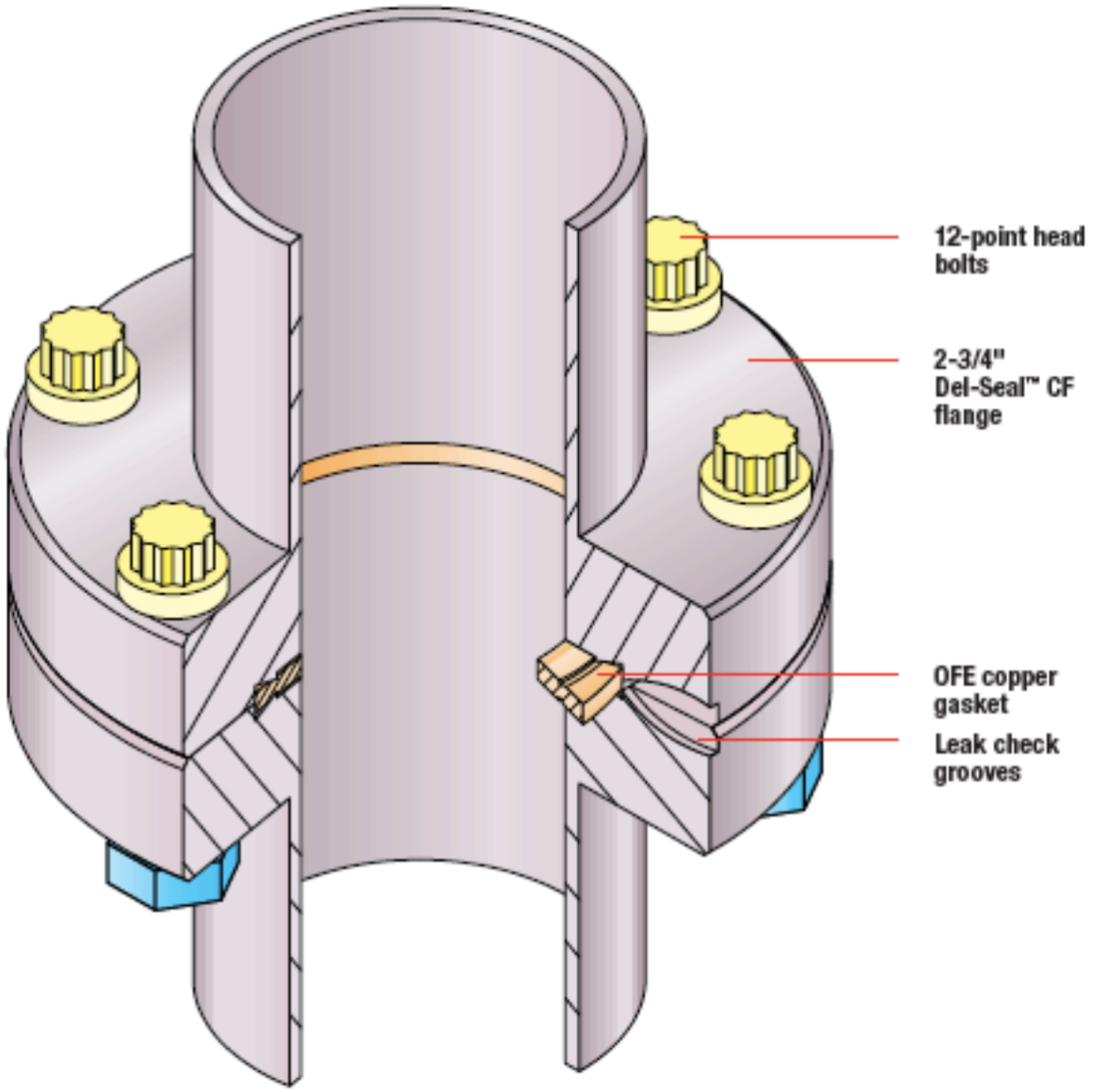
OFE copper gasket

Two required

Double sided flange

Typical use:
- Access flange
- Butterfly valve
- Shutter
- Spacer

Chamber port

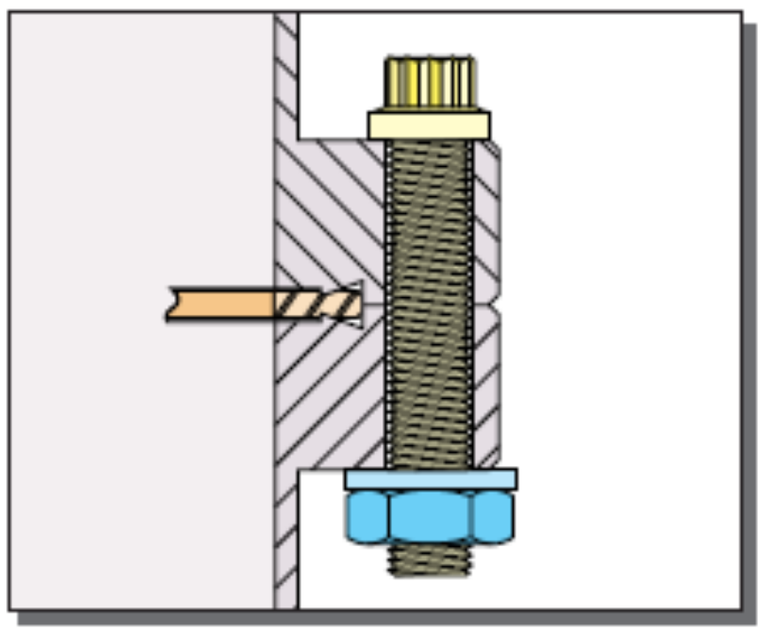


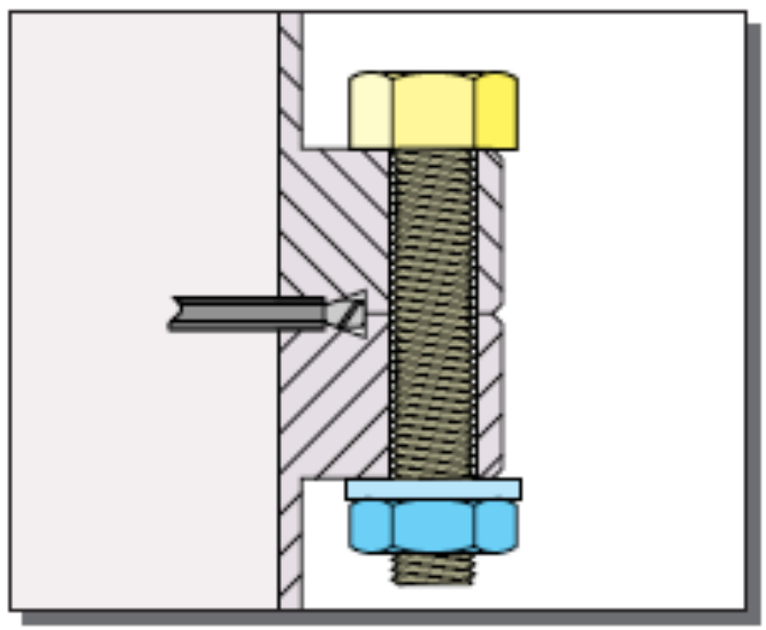
12-point head bolts

2-3/4" Del-Seal™ CF flange

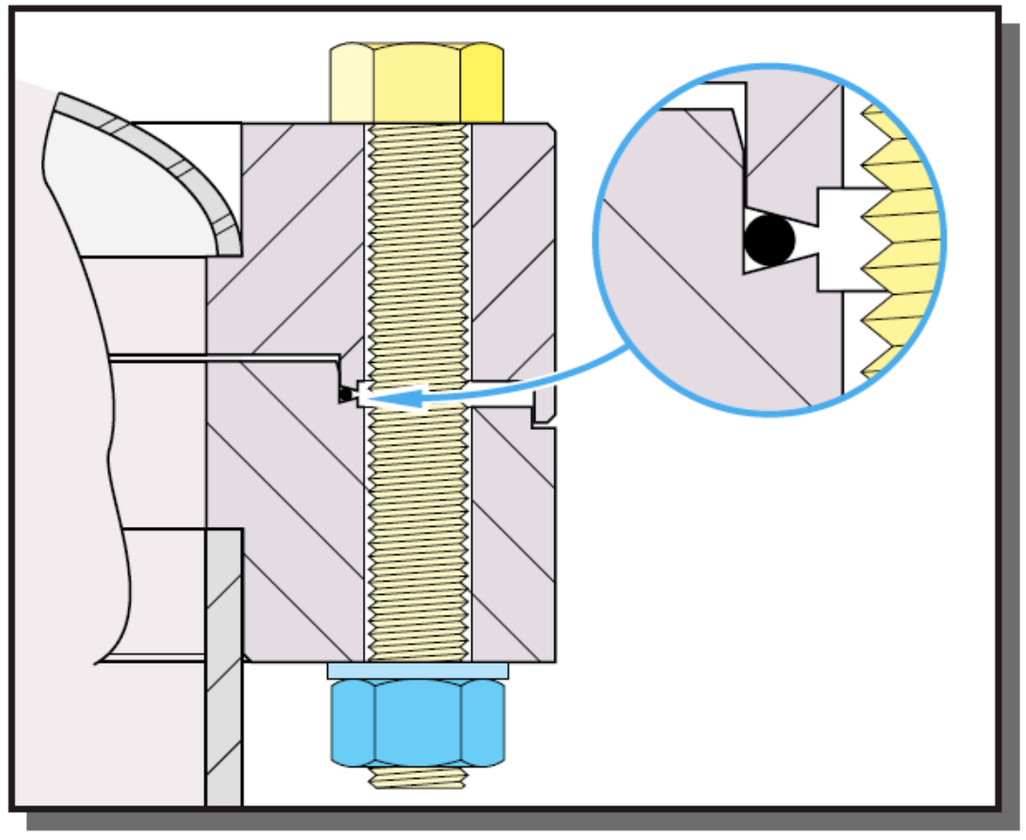
OFE copper gasket

Leak check grooves

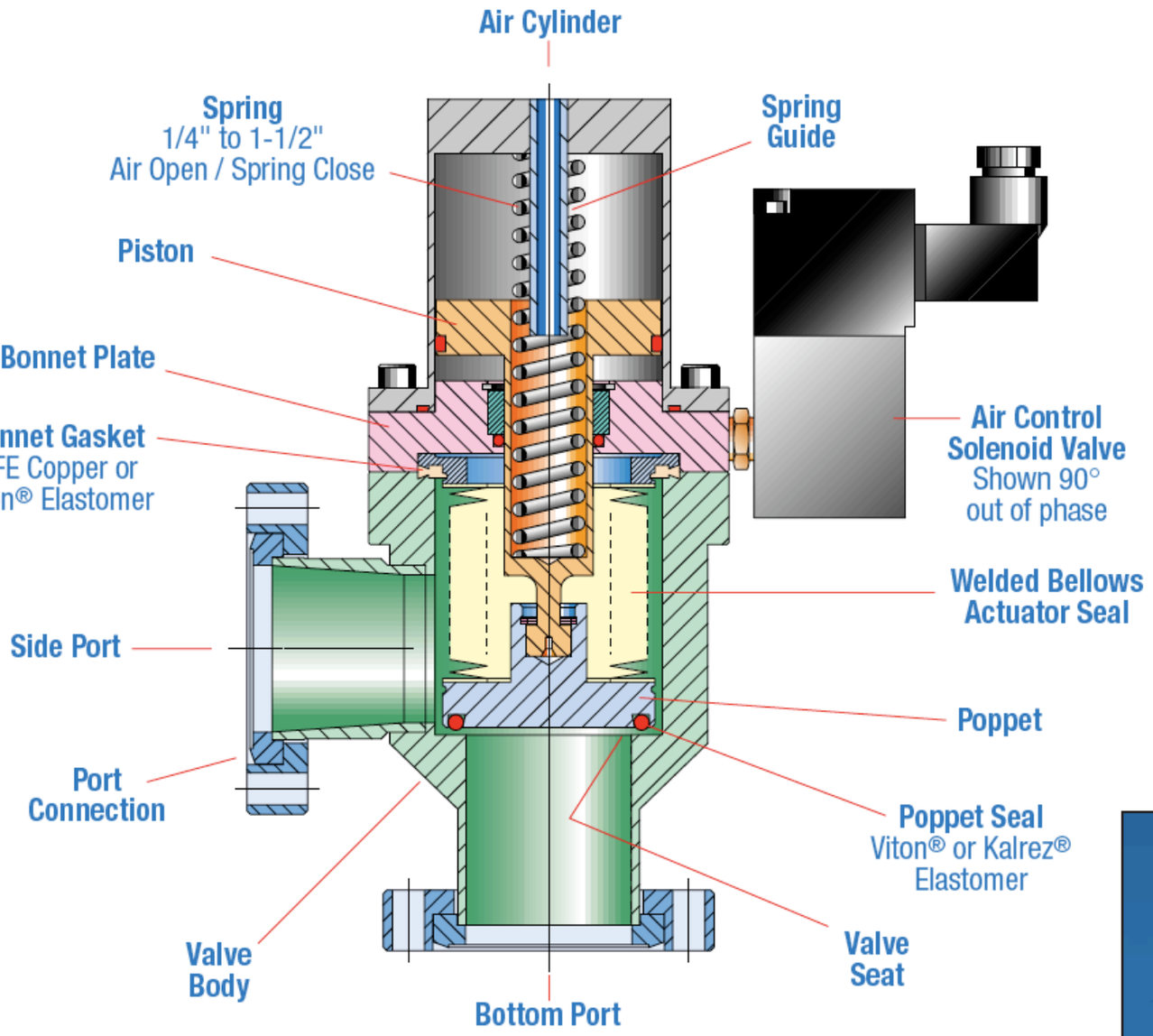


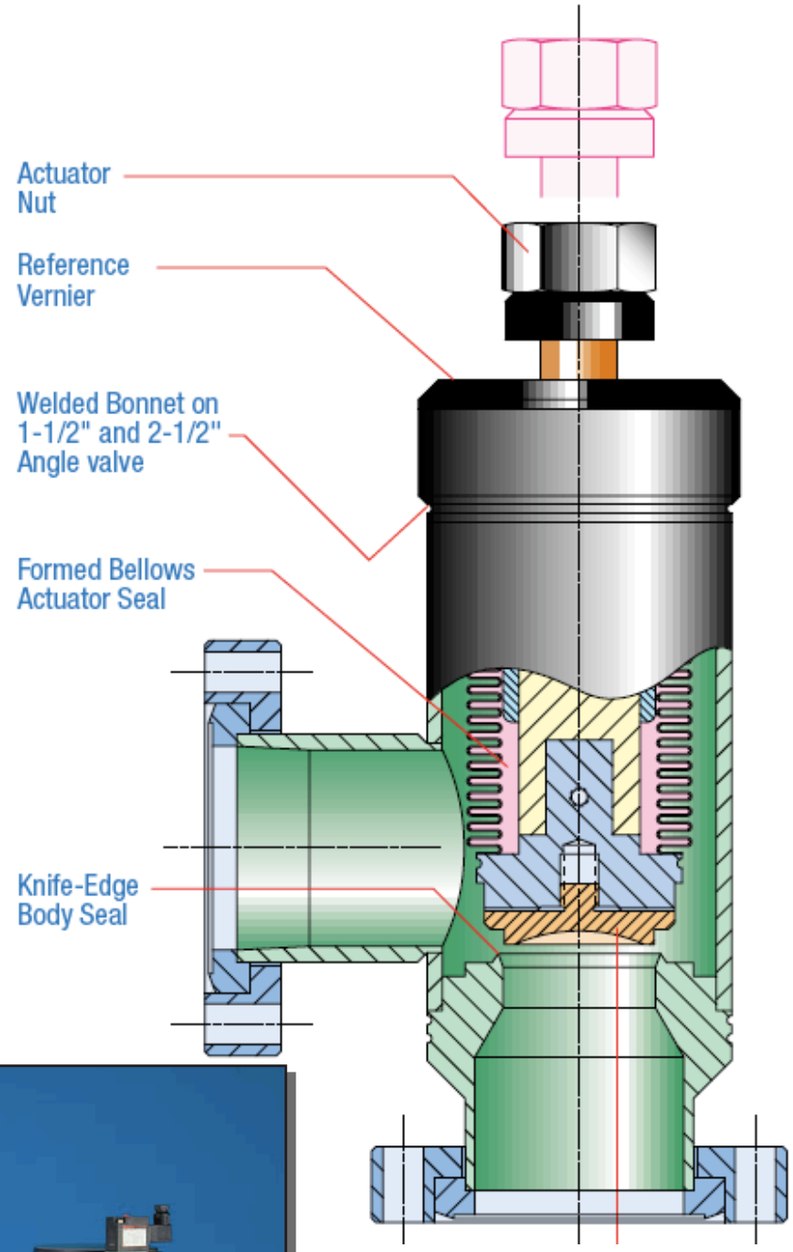


Wire seal for large diameters >16"



90° valves





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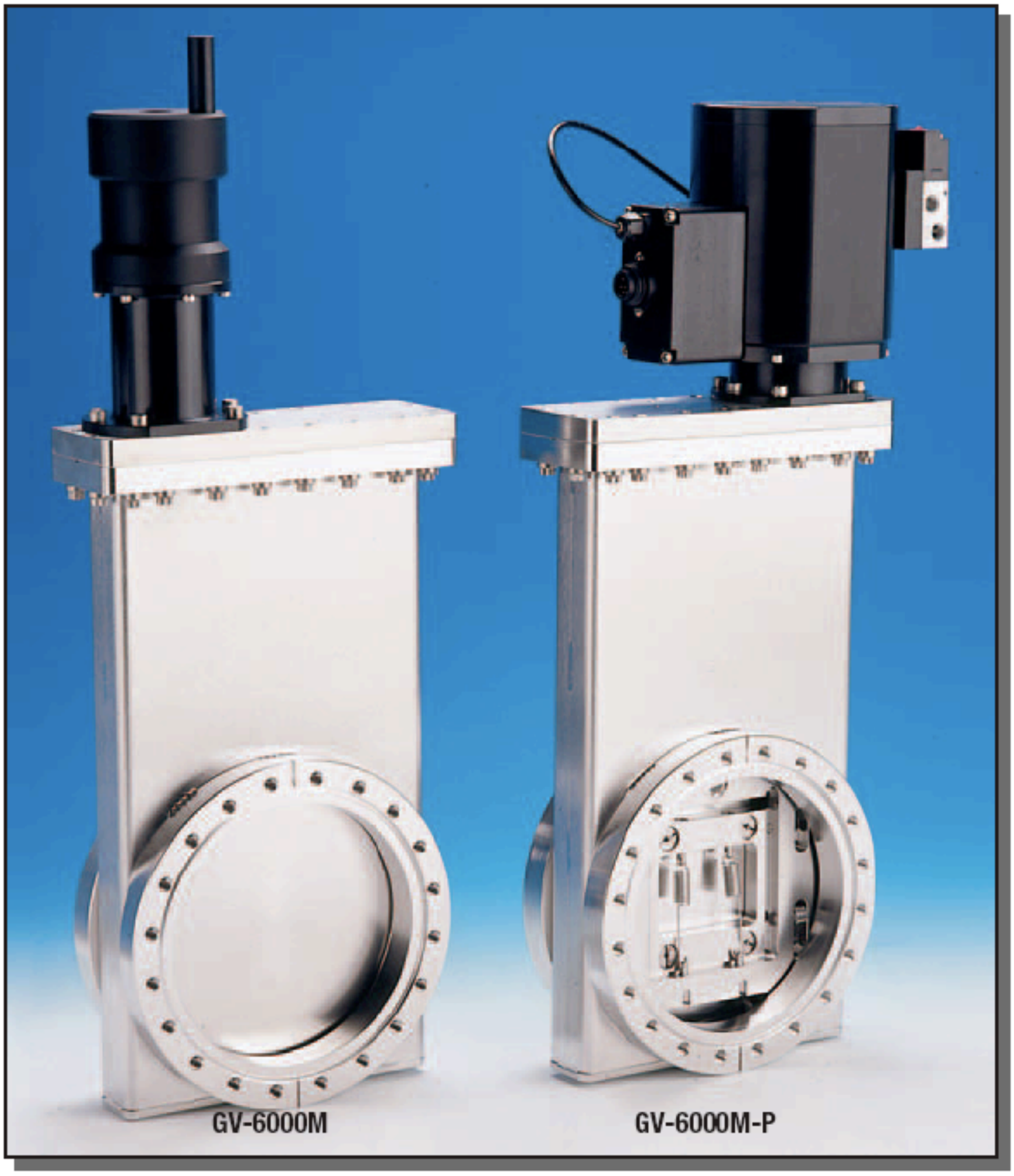
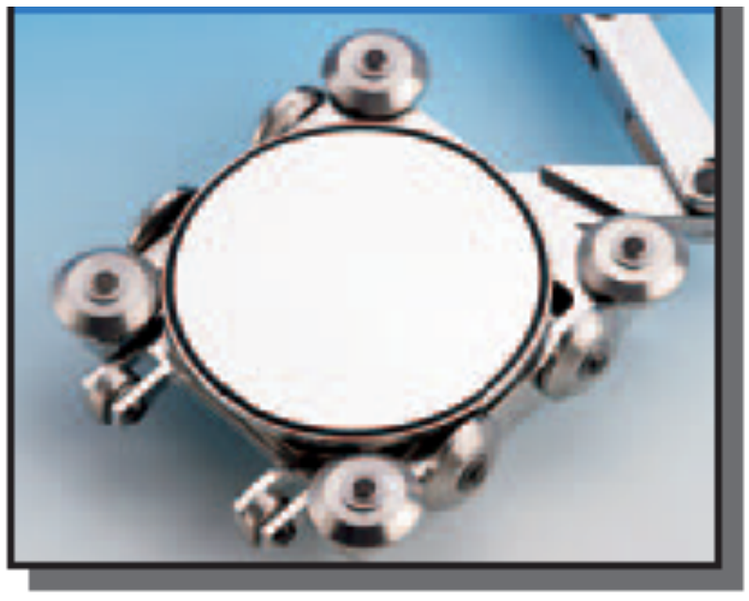
Gate valves



Del-Seal™ CF

10" Del-Seal CF



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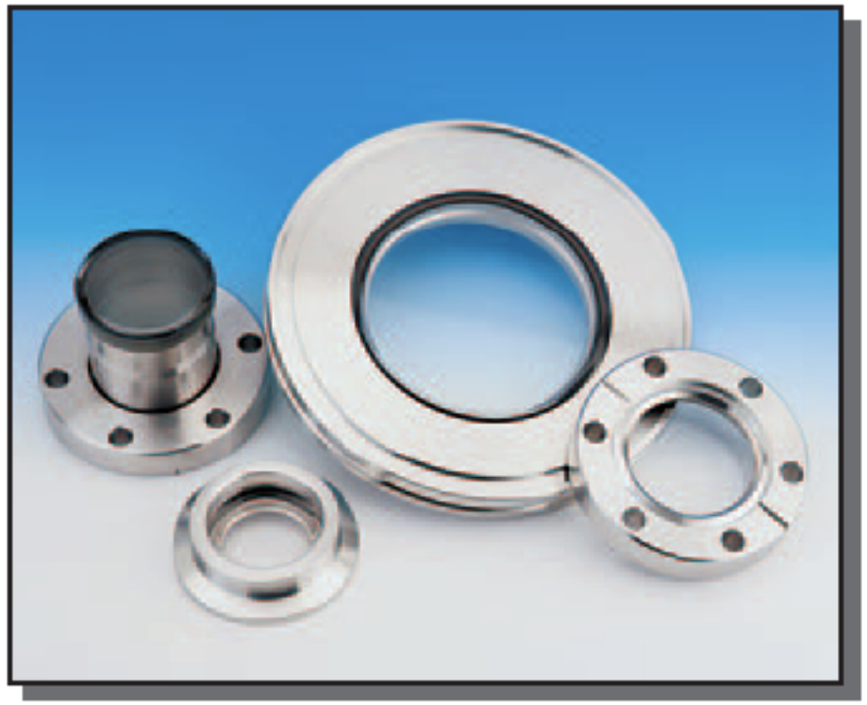
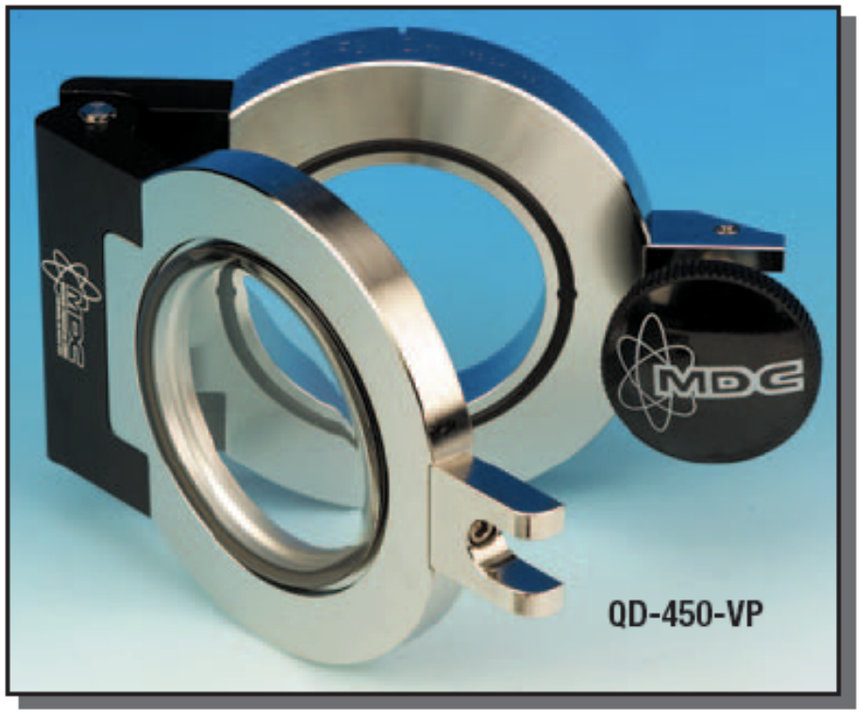
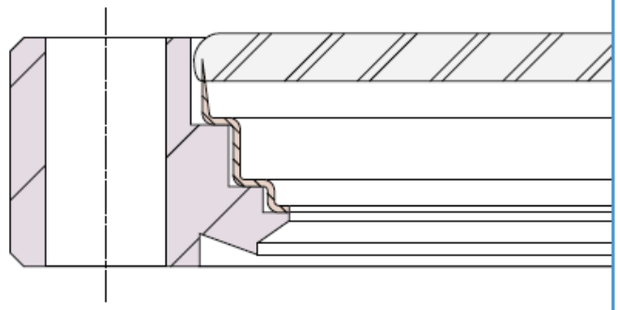
Viewports





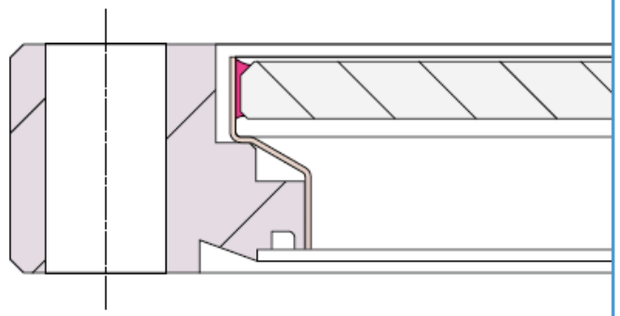
Glass

Glass is fused to a thin nickel-iron metal transition



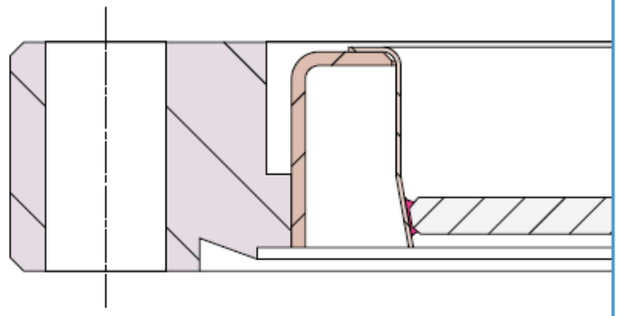
Quartz

Quartz is metalized and brazed directly to stainless steel using a lead-silver braze alloy



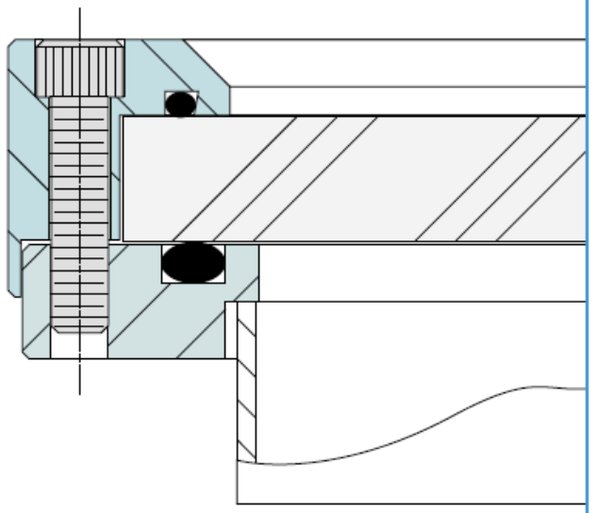
Sapphire

Sapphire is metalized and vacuum brazed to a nickel-iron sleeve using a tapered seal interface

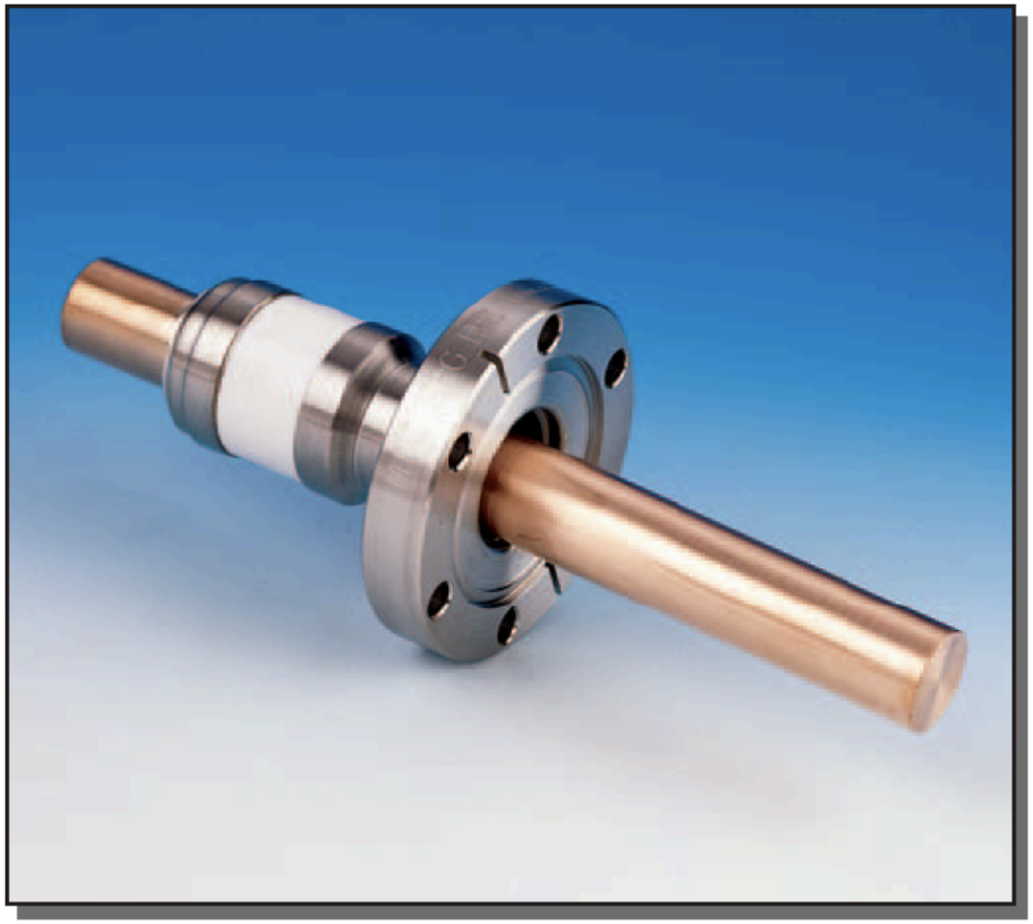


Pyrex®

A Pyrex® substrate is sandwiched between two elastomer seals. The outer elastomer (top in drawing) is for cushioning and the inner elastomer (bottom in drawing) makes the vacuum seal.



Electrical feedthru's



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Motion feedthru's

Rotary

BRM-133

Linear

BLM-133-1

Rotary +Linear

Linear Drive

PBRM2-10

Wobblestick

Blank Jaws

DG-275
Patented Design

Sample manipulation

Precision Rotary-Linear drives can be found on page 404

Extended length rotary drives can be found on page 380

V-Plane® Guide Tubes include four 1-1/3" Del-Seal™ CF ports for electrical accessories

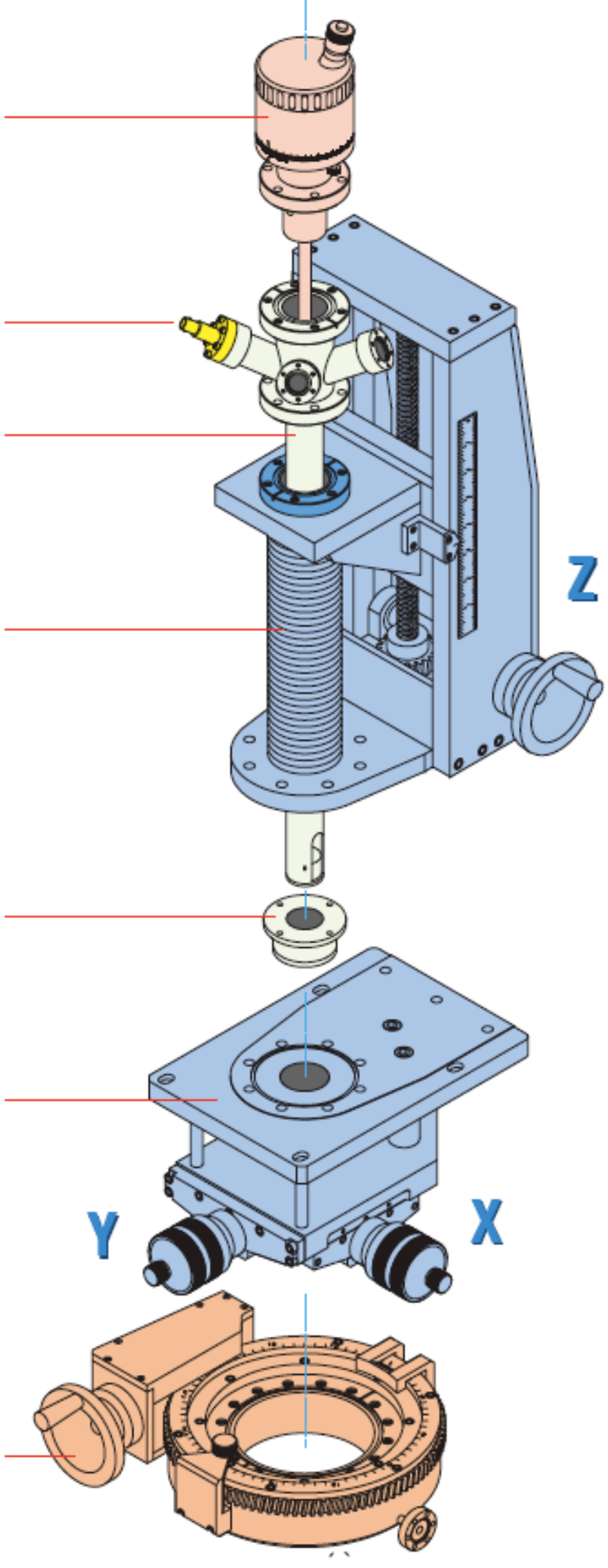
V-Plane® Guide Tubes can be found on page 420

V-Plane® Z axis stages can be found on page 418

Linear and rotary bearing guides are included with the guide tubes

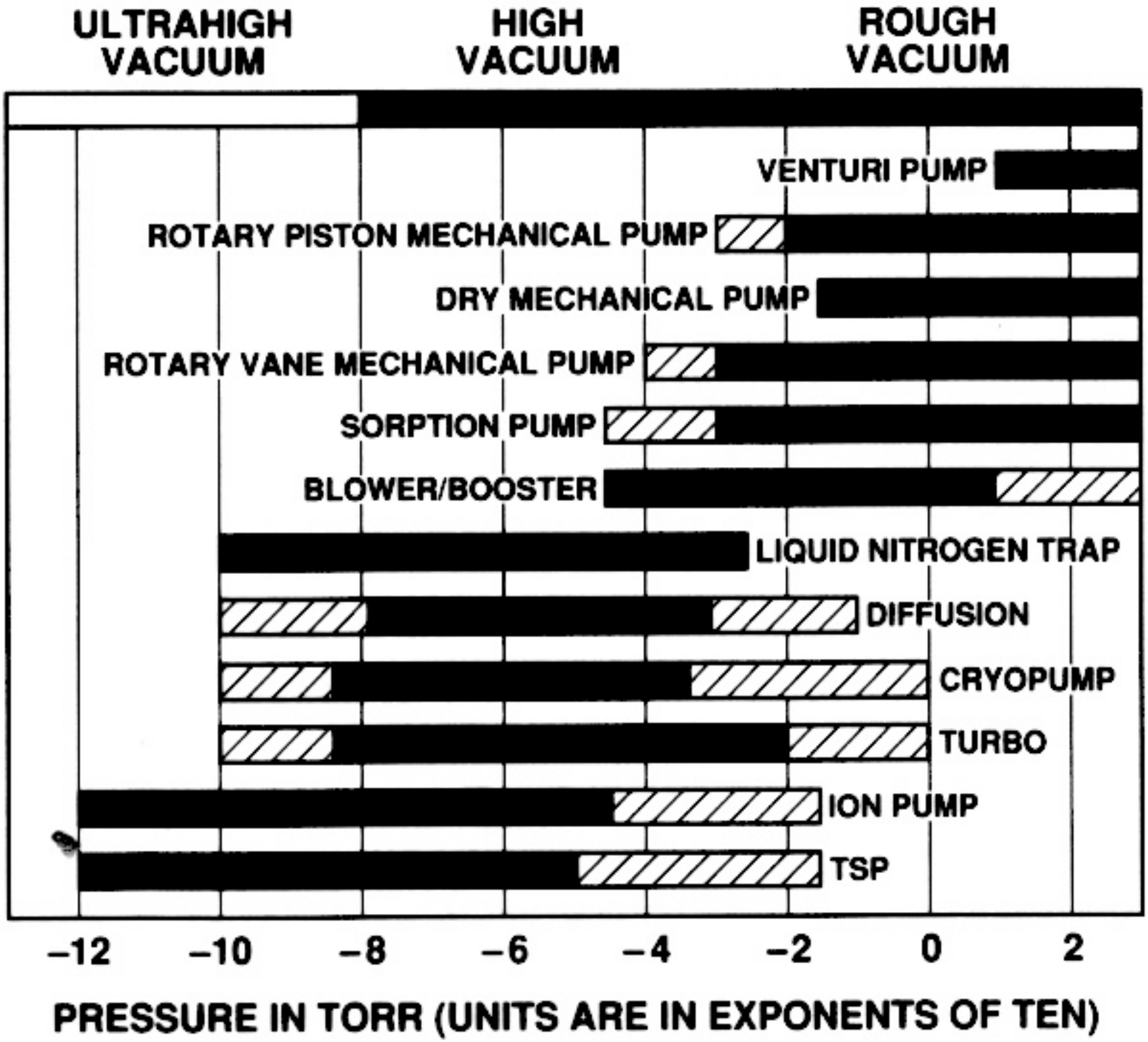
V-Plane® Dual axis XY stages can be found on page 416

Rotatable stages provide 360° of positioning and can be found on page 428



PUMPS

PRESSURE RANGES OF VARIOUS PUMPS



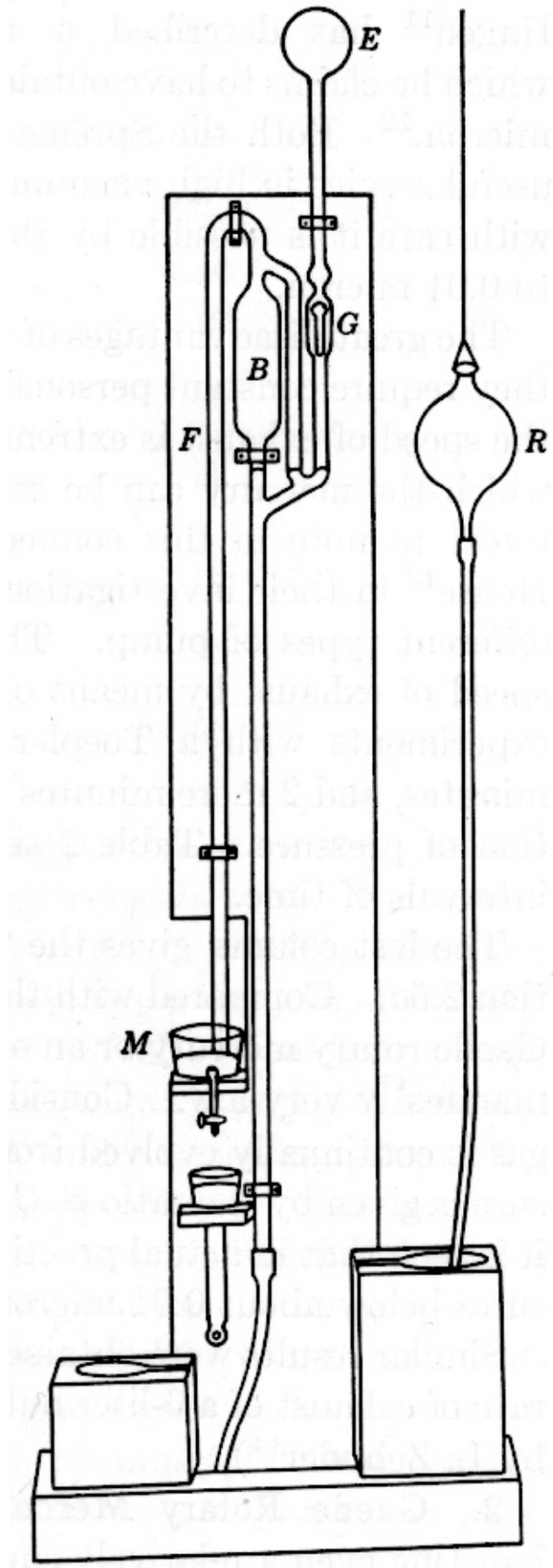
Roughing pumps

discharge at to atmospheric pressure

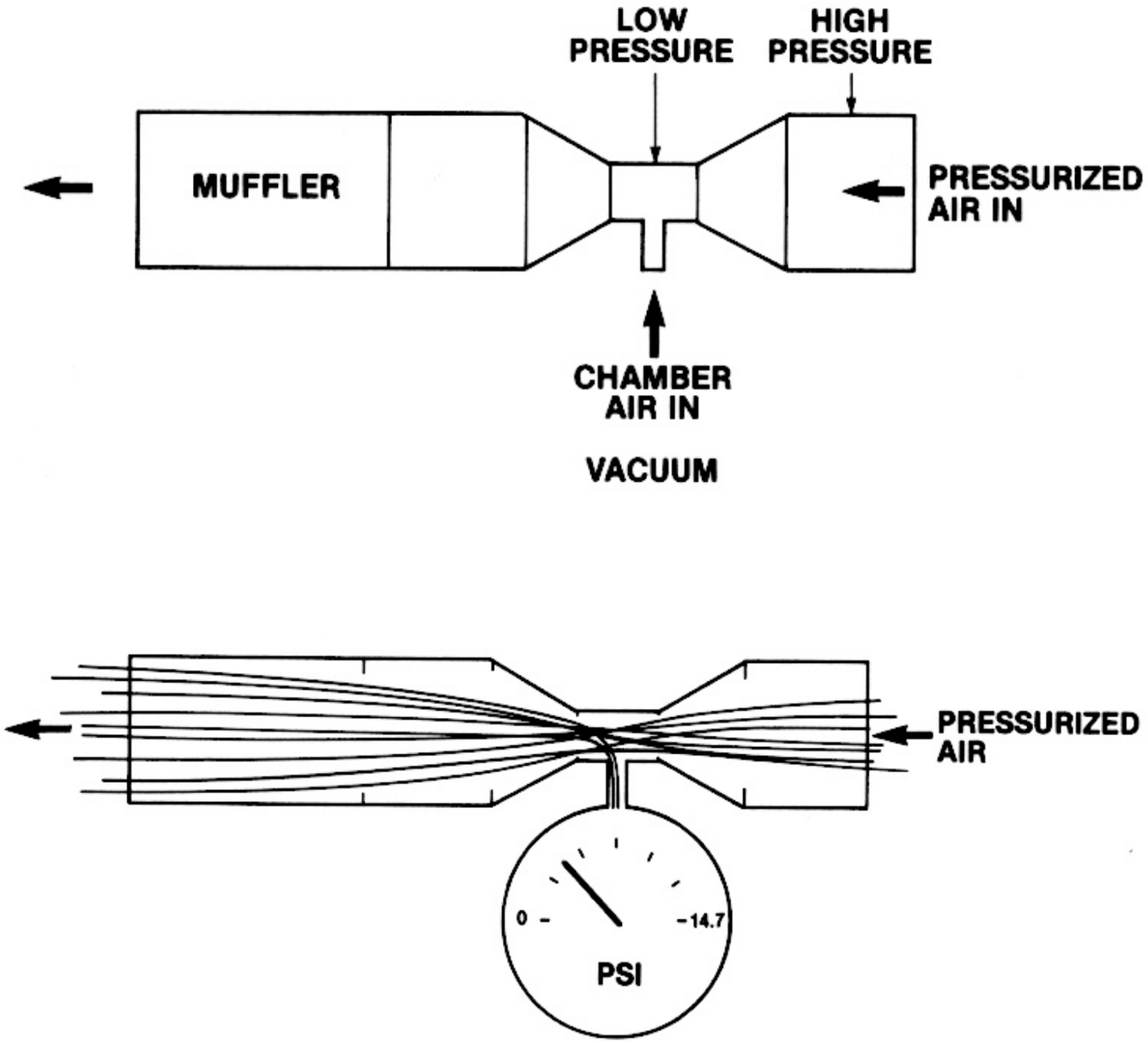
pumping speed 1-1000 cfm

ultimate pressure 1-10^{-3} Tr

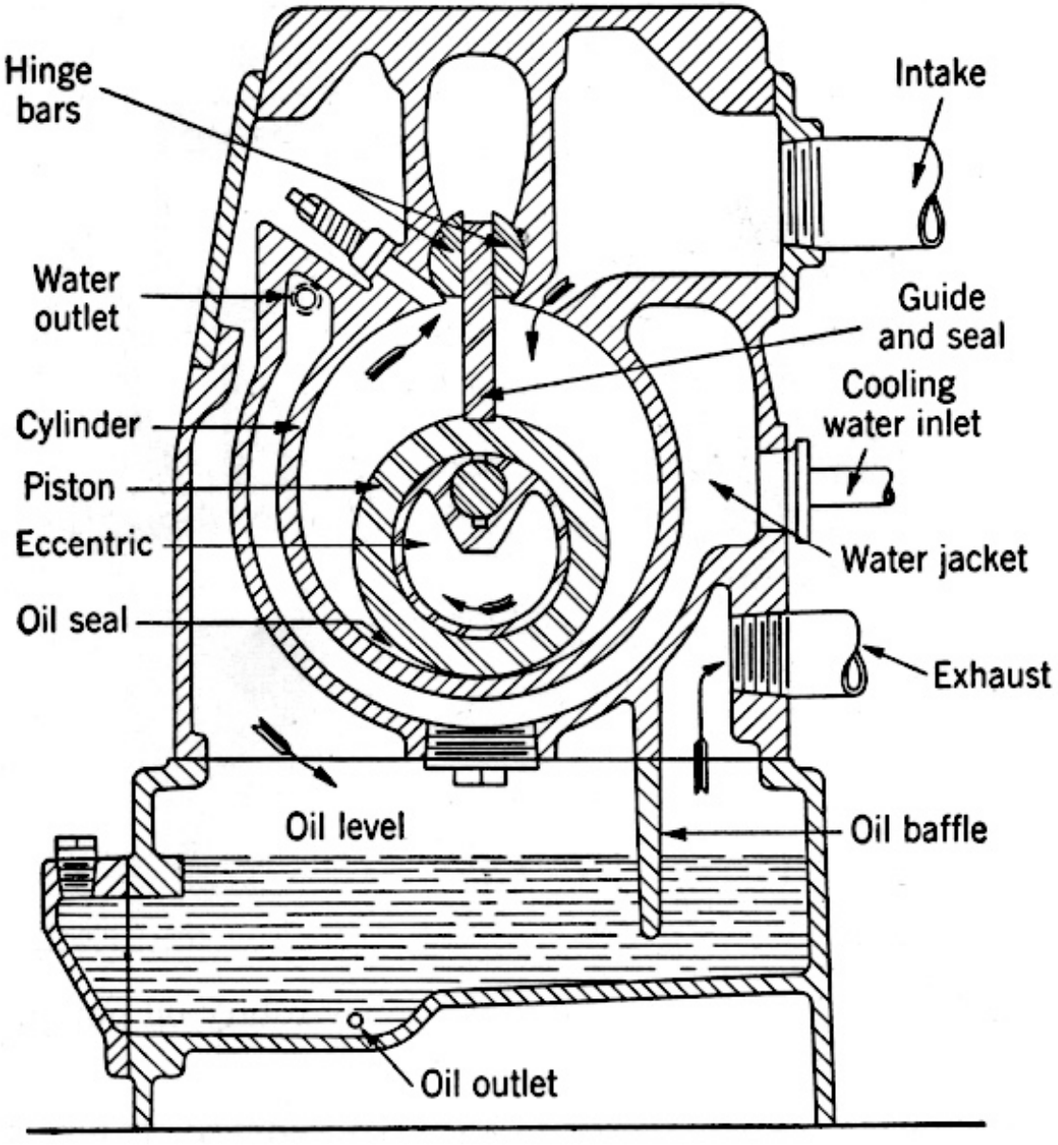
manual Toepler

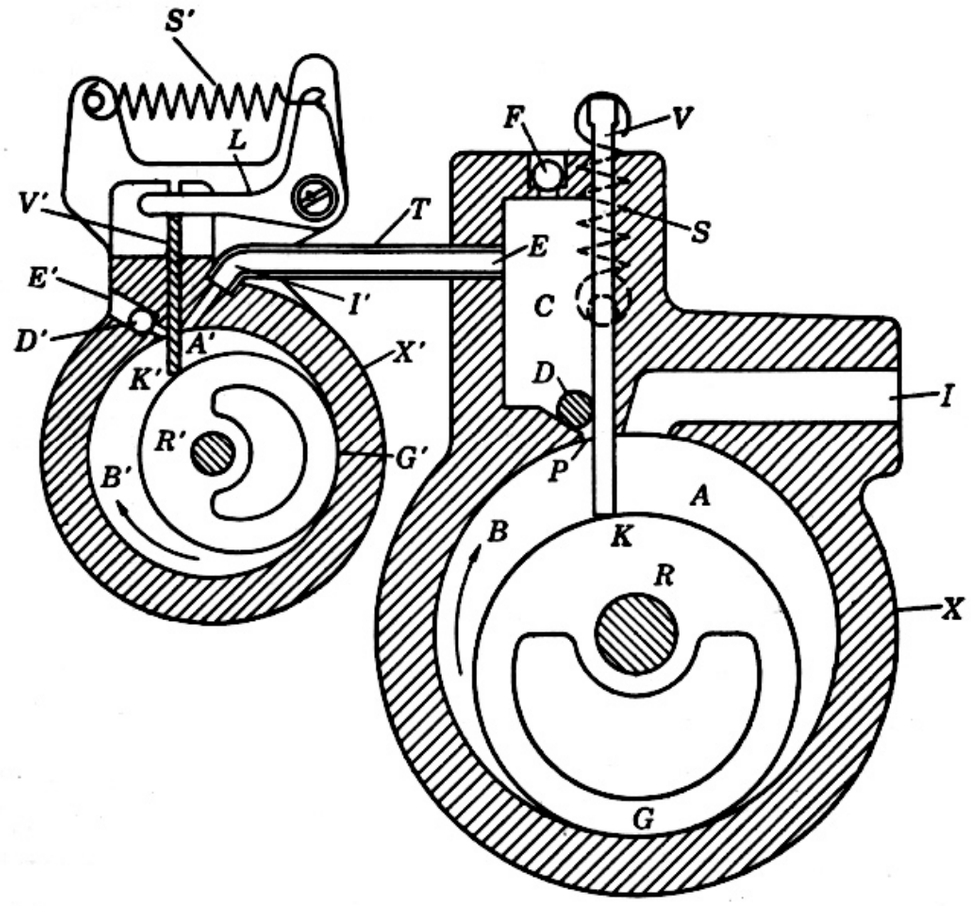


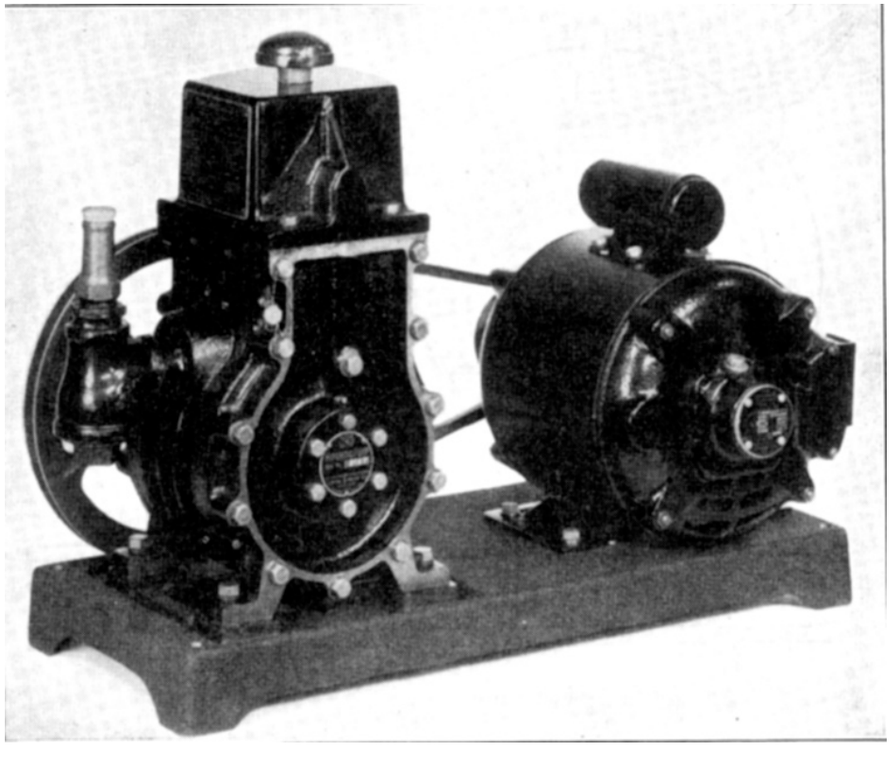
Venturi



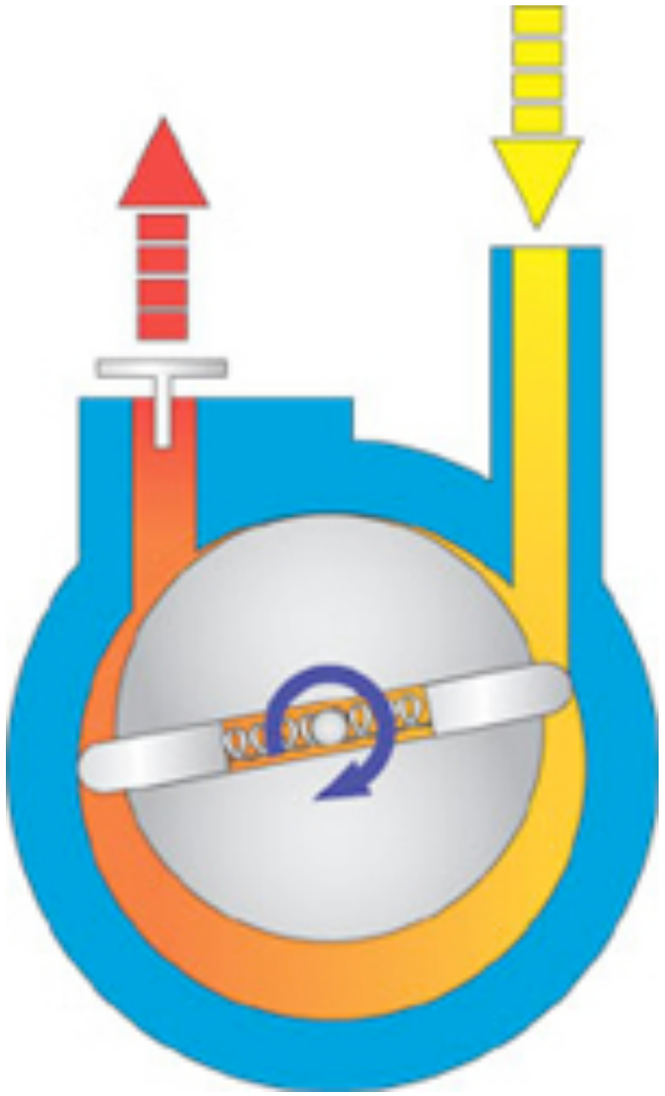
Rotary Stokes pump

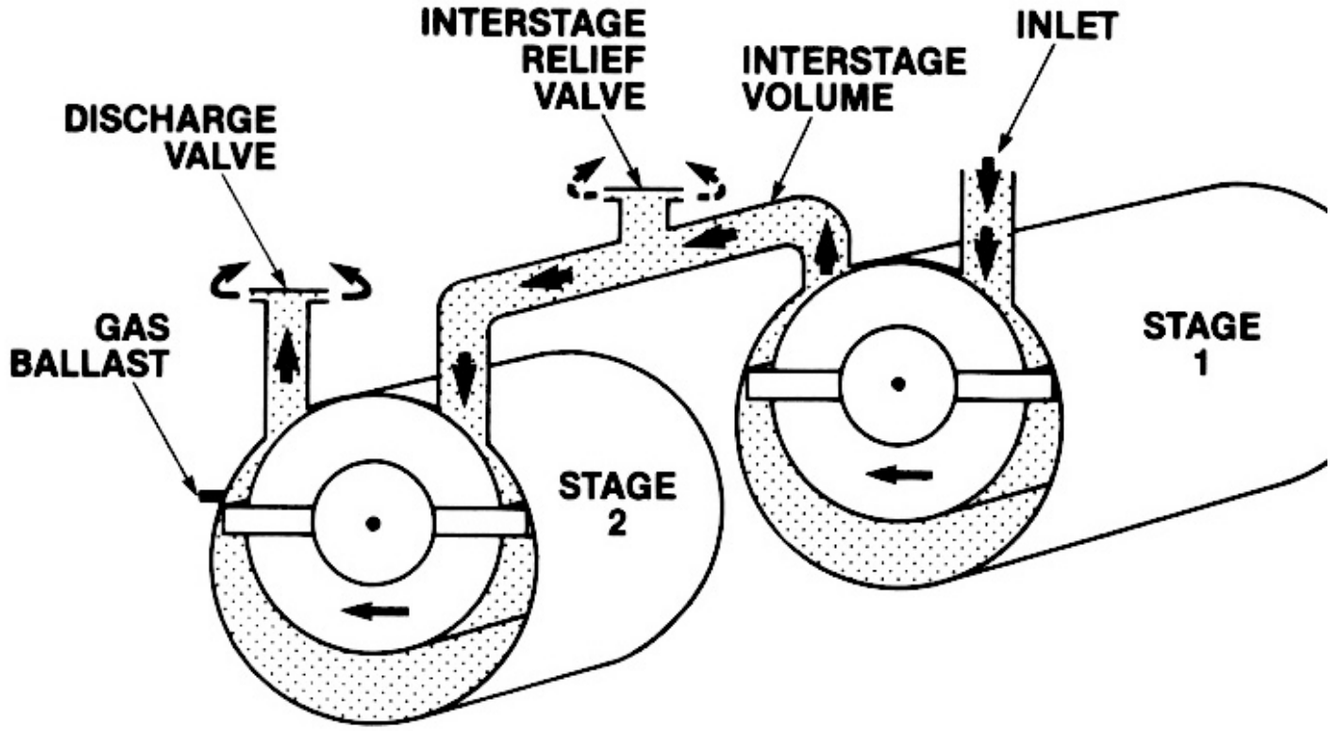


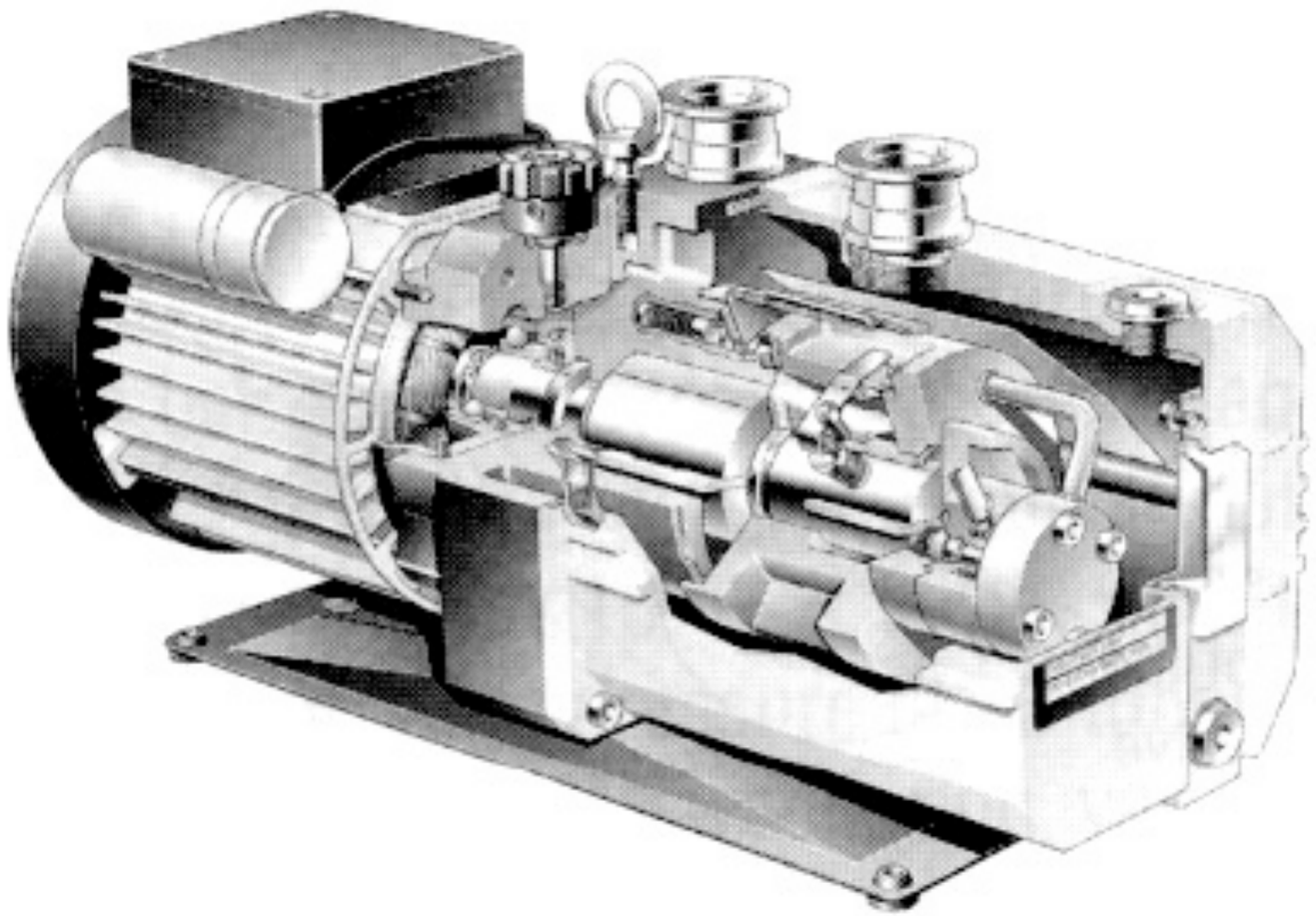


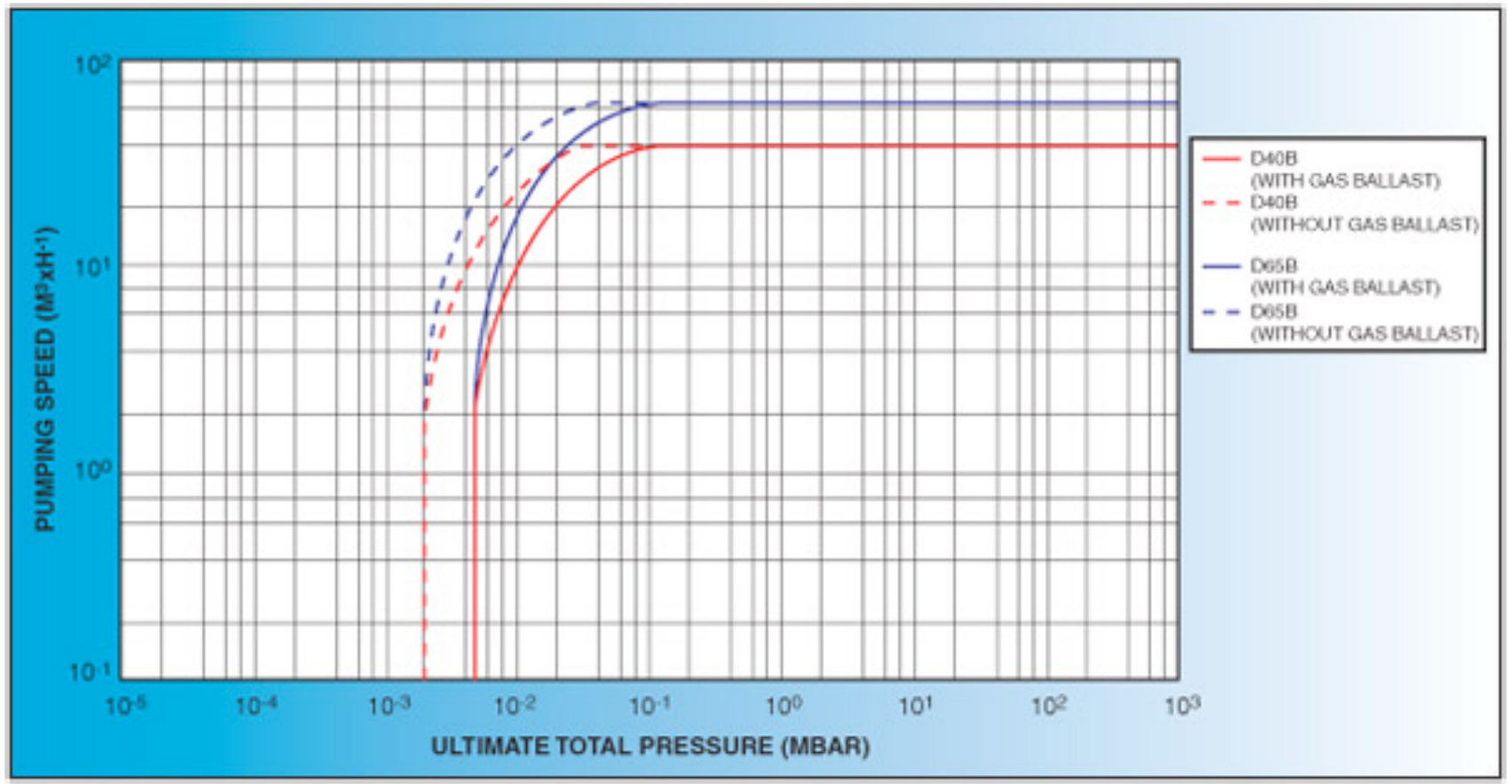


Rotary vane pumps

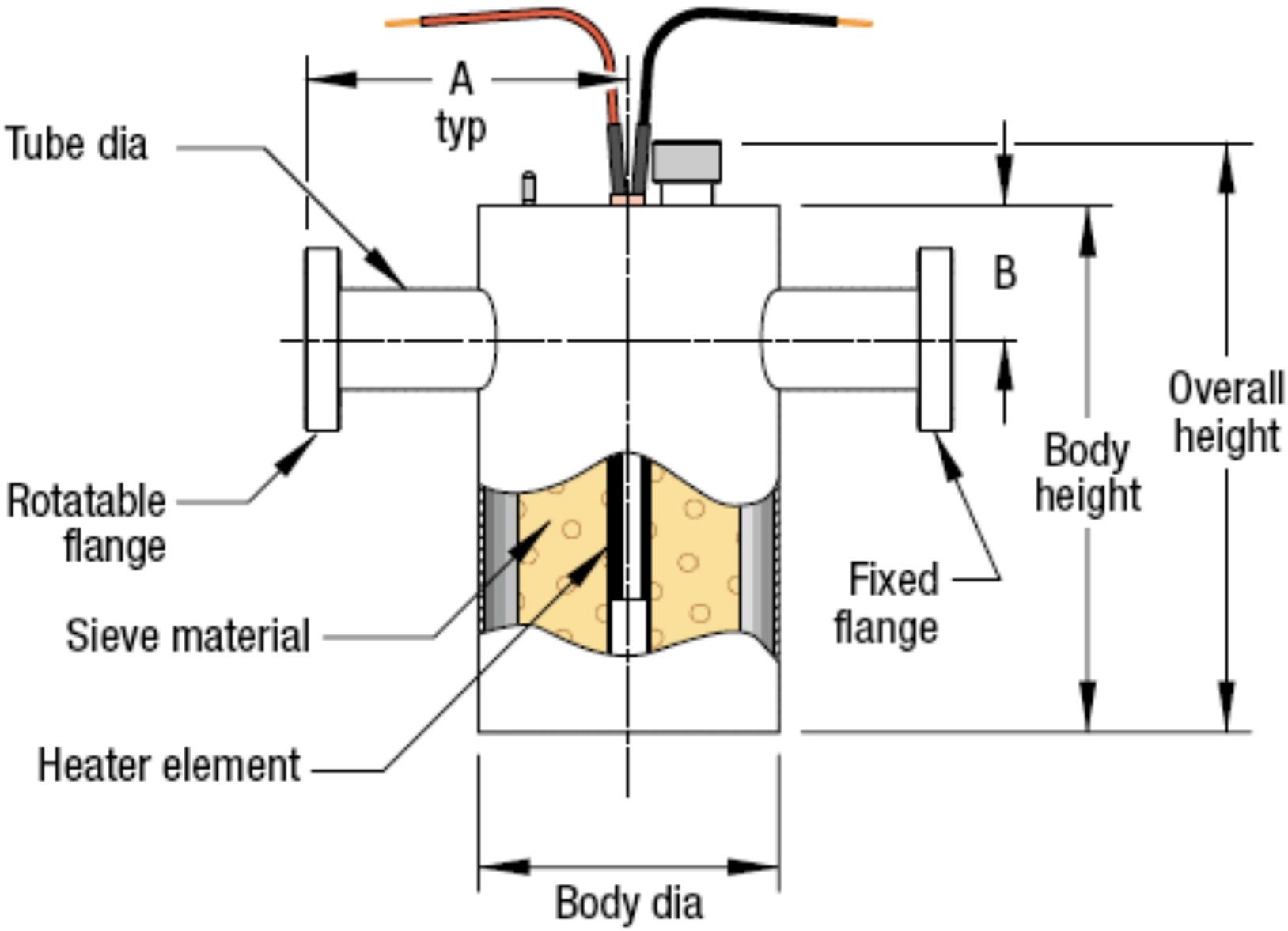




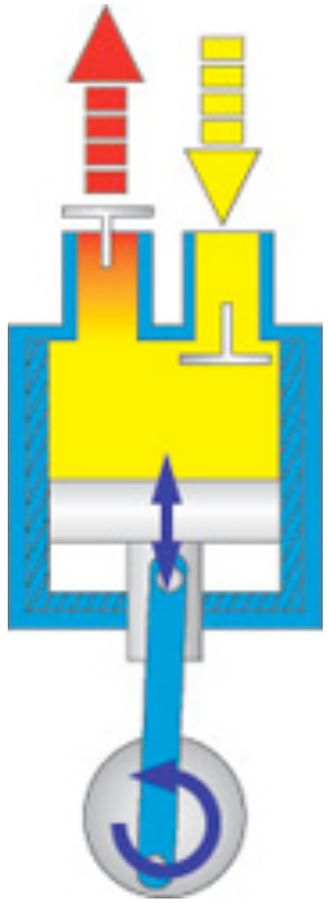


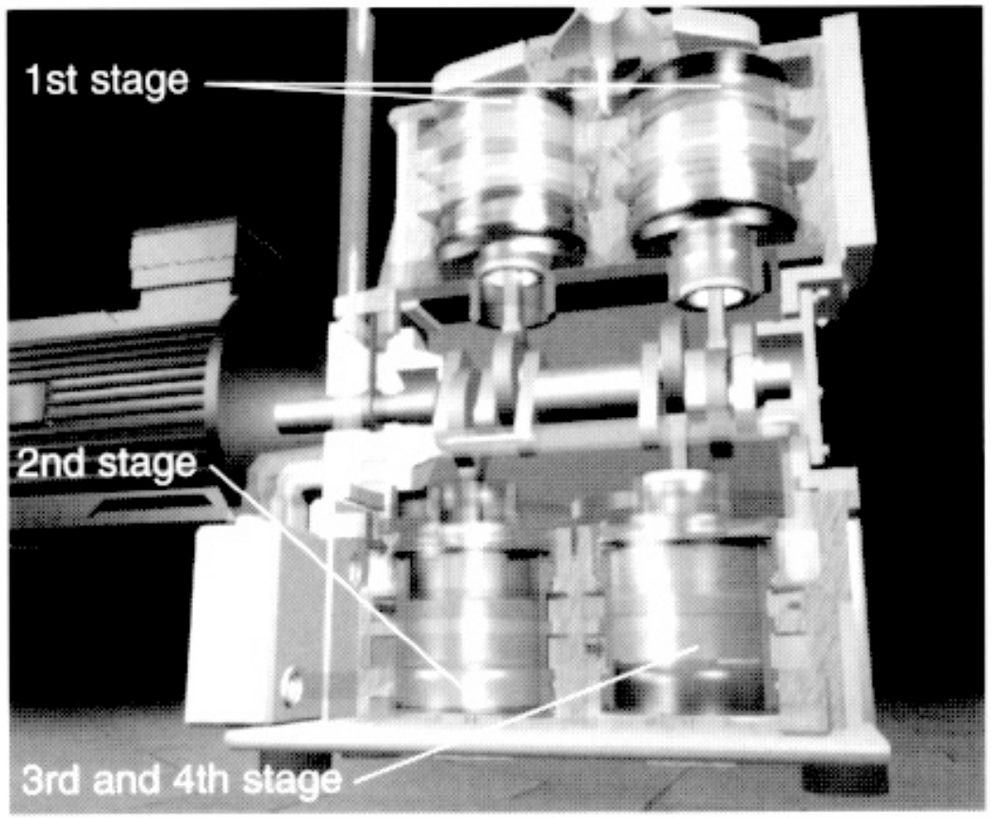


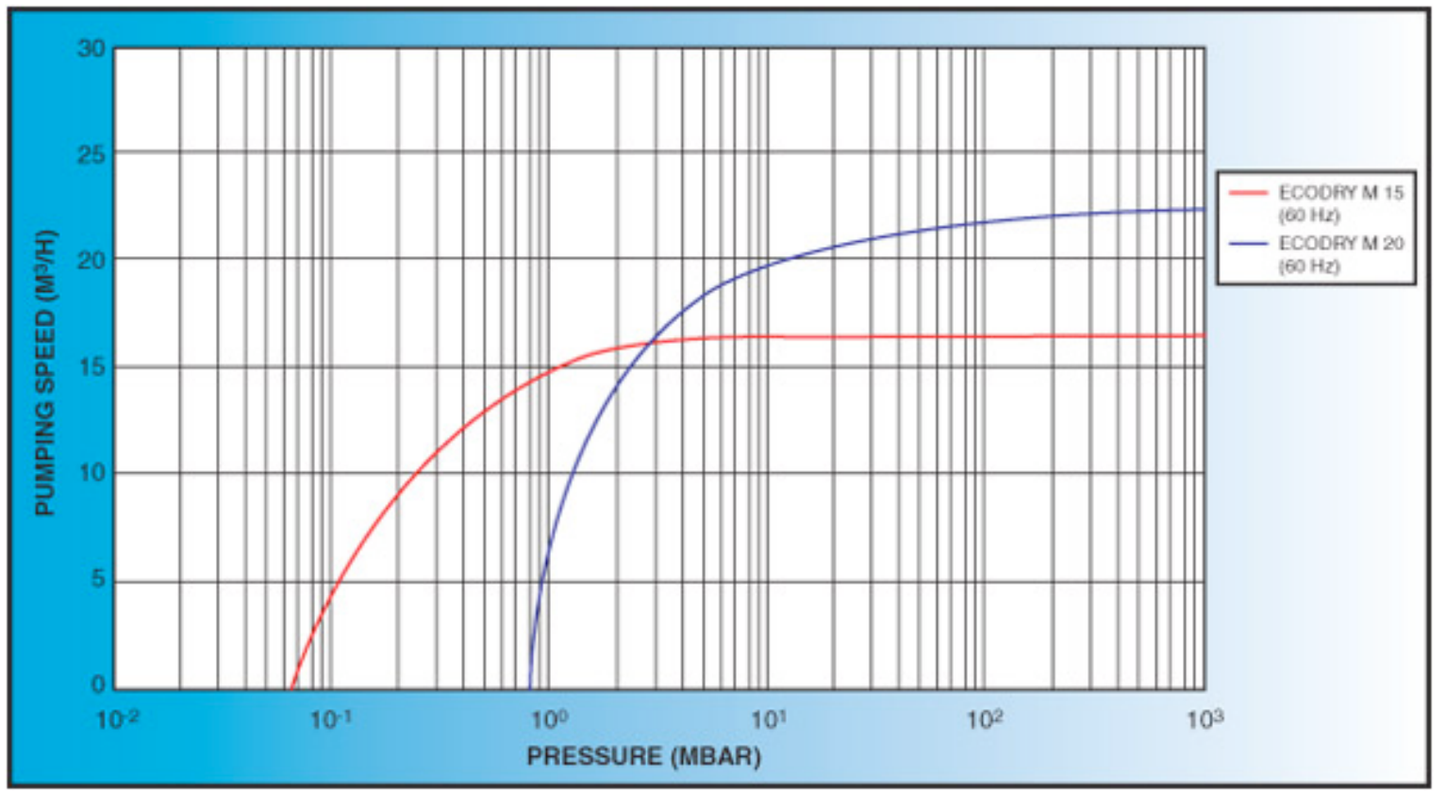
Oil trap


A
typ
Tube dia
B
Overall
height
Body
height
Rotatable
flange
Fixed
flange
Sieve material
Heater element
Body dia

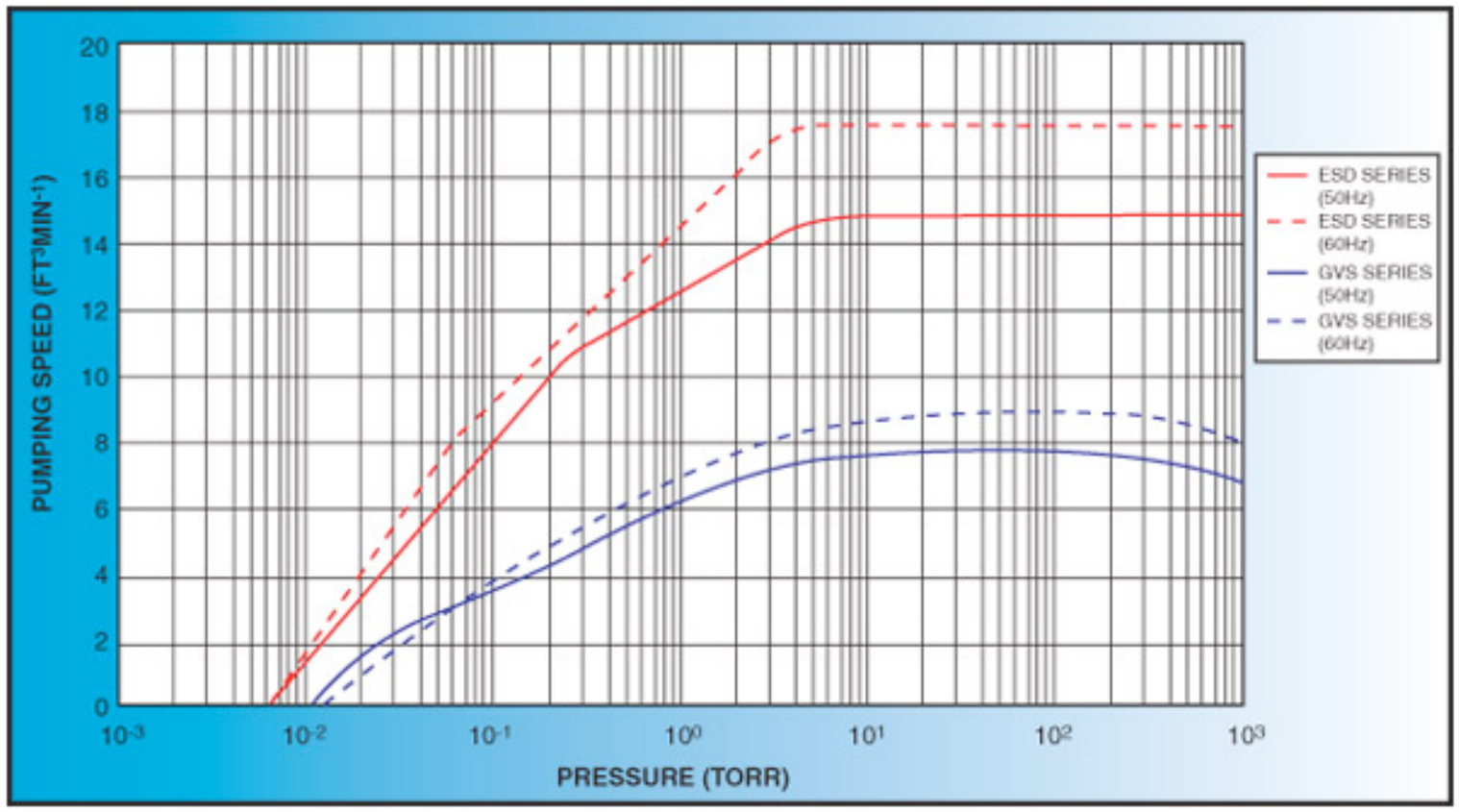
Dry piston pump



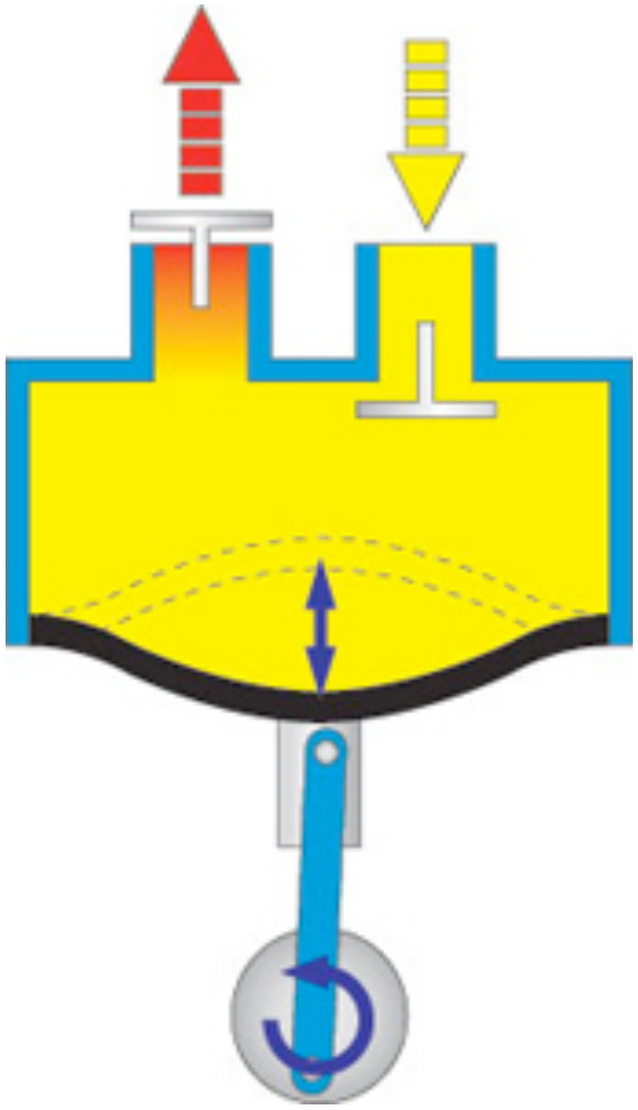


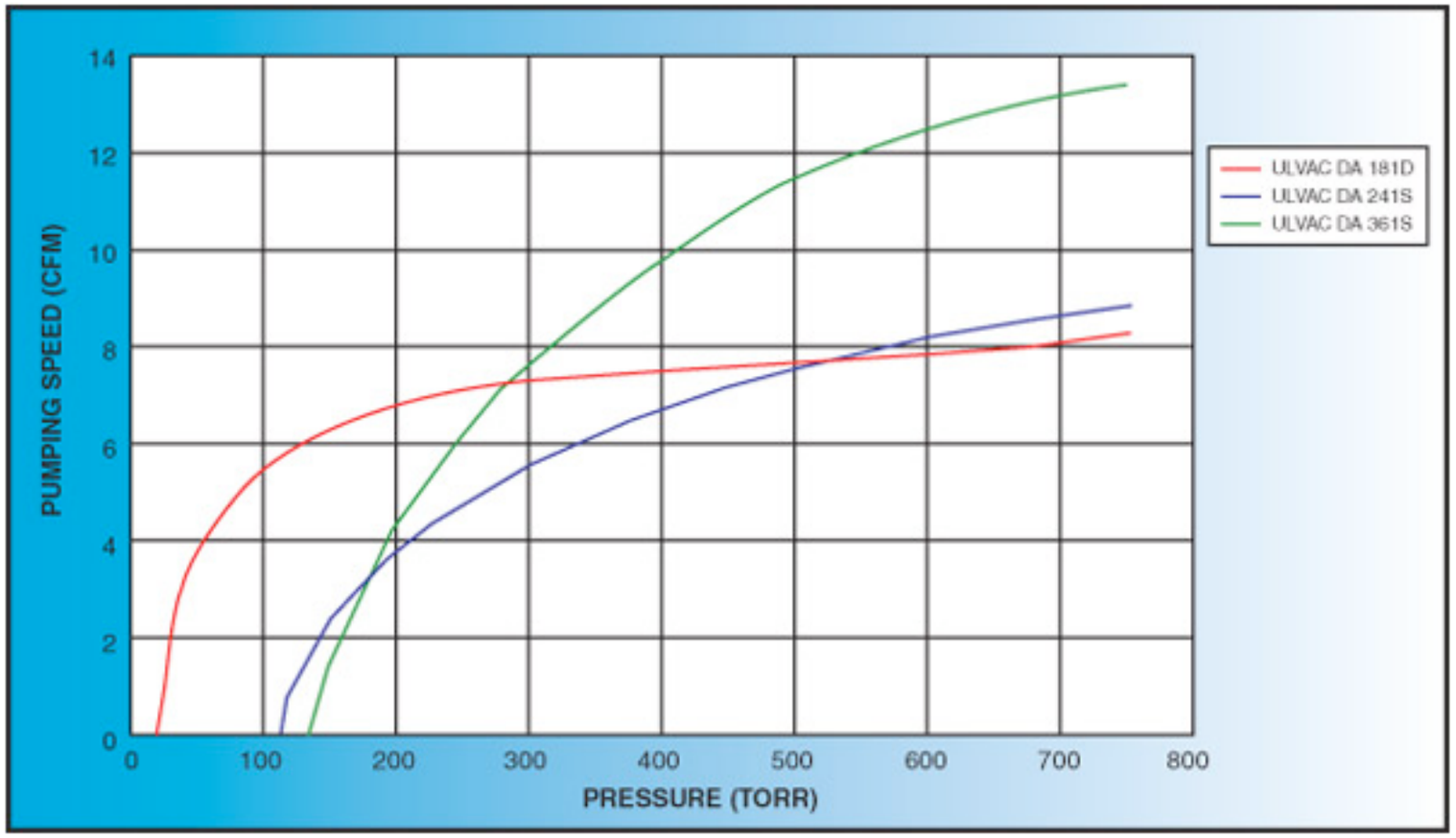


Dry scroll pump

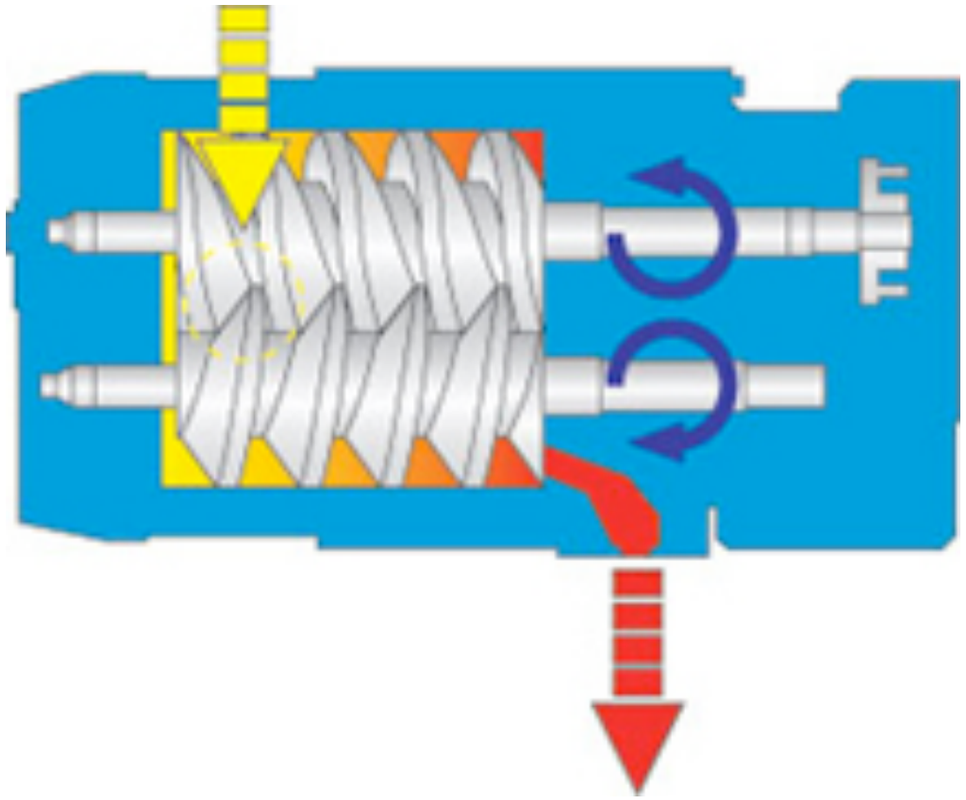


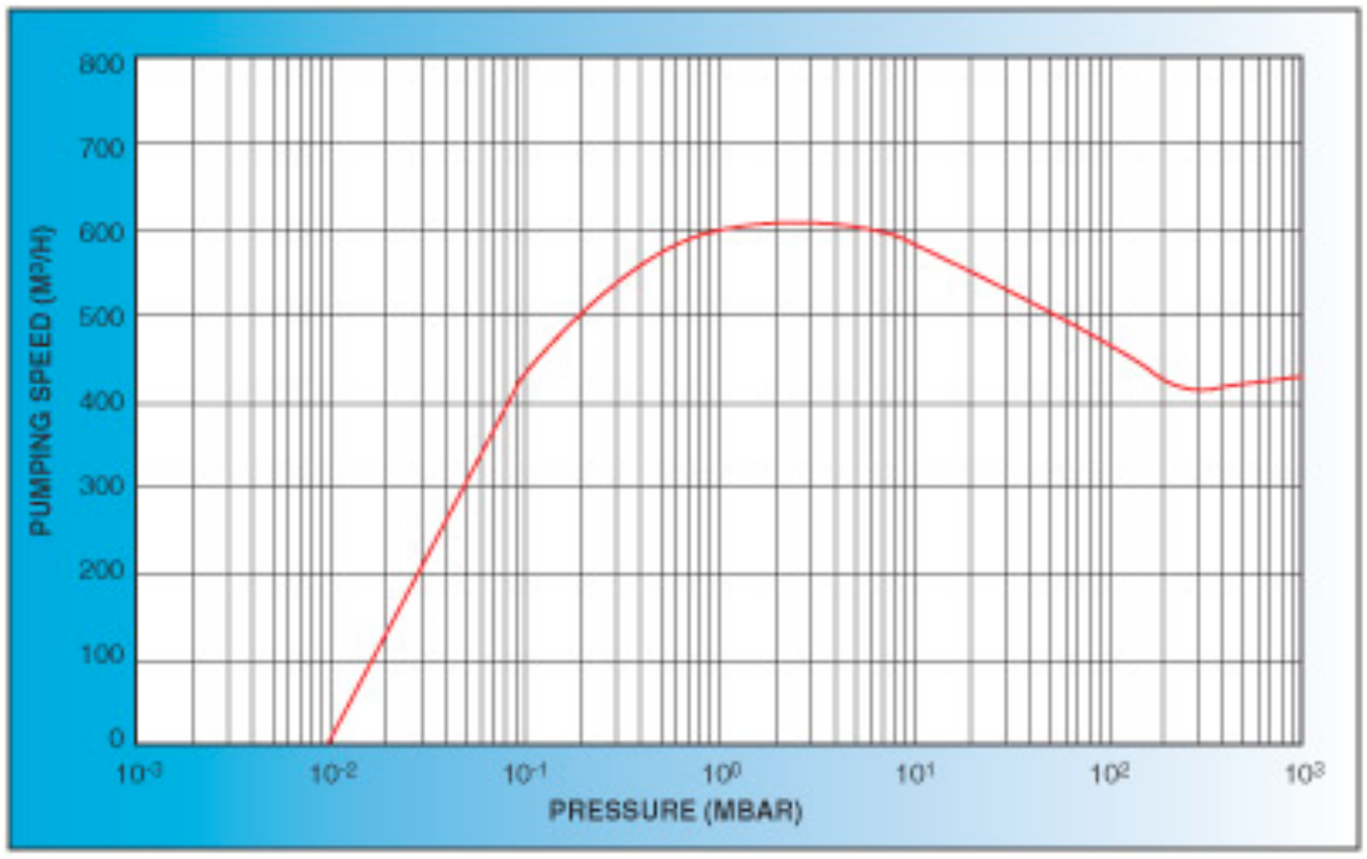
Dry diaphragm pump



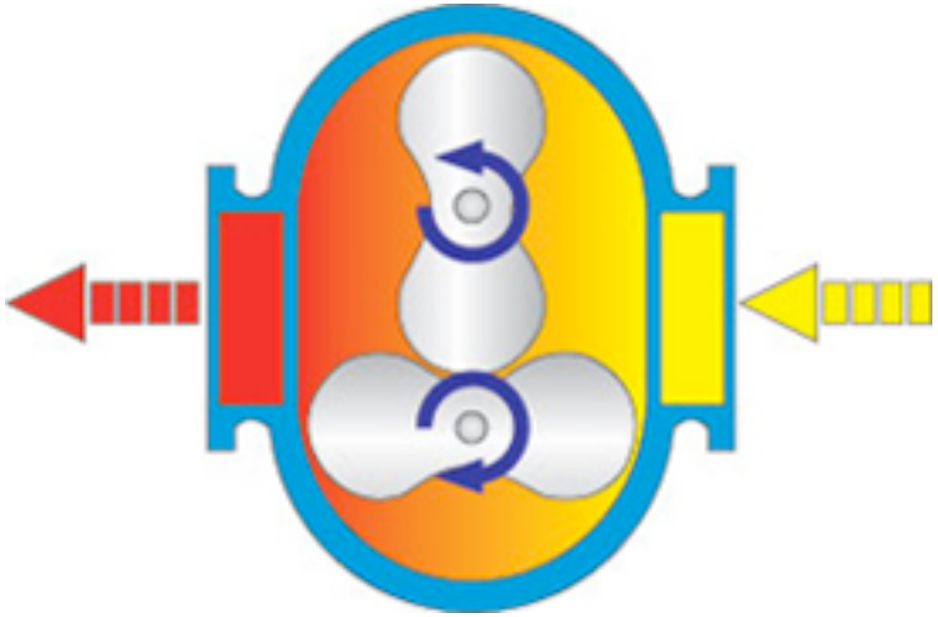


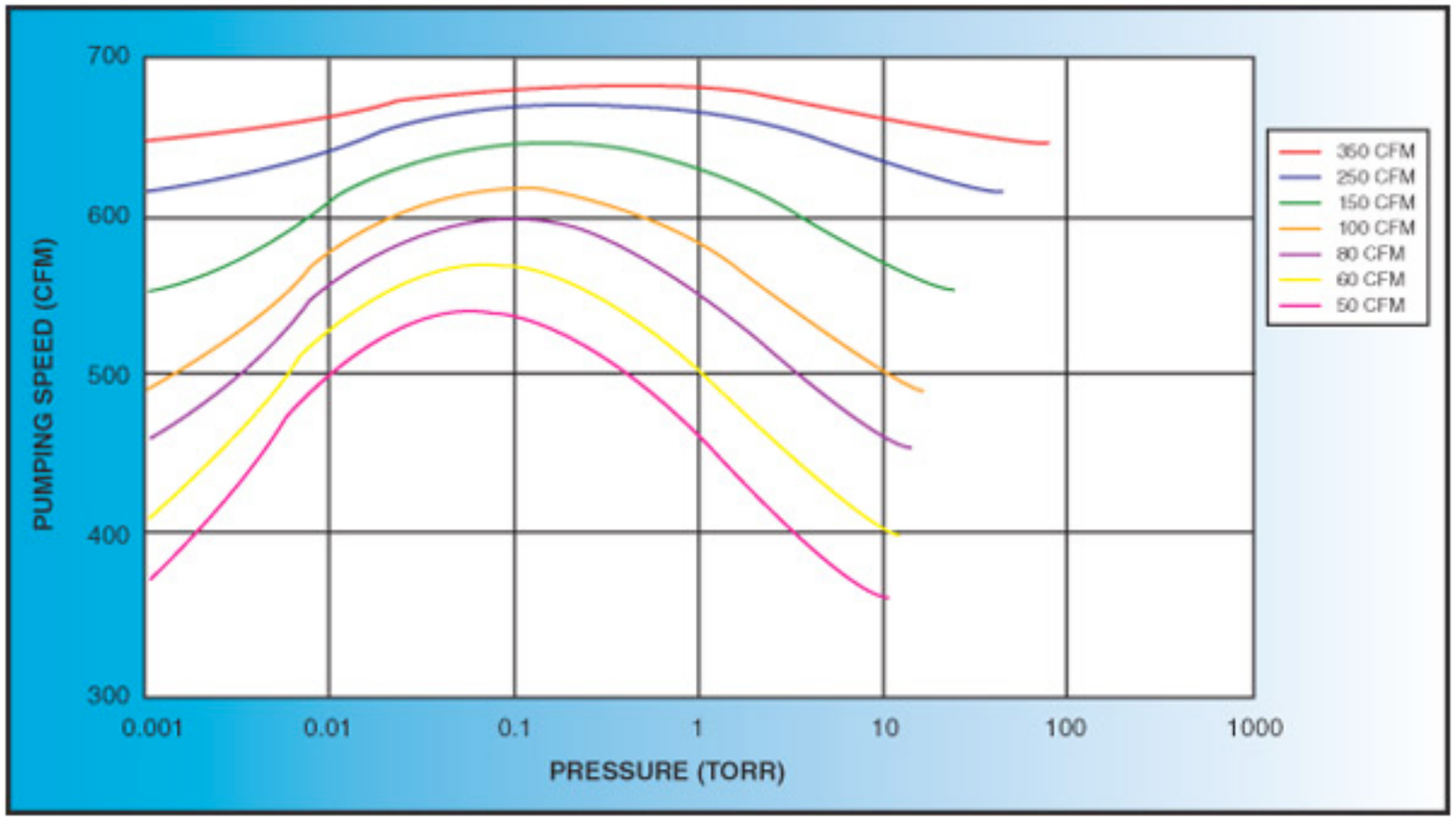
Dry screw pump



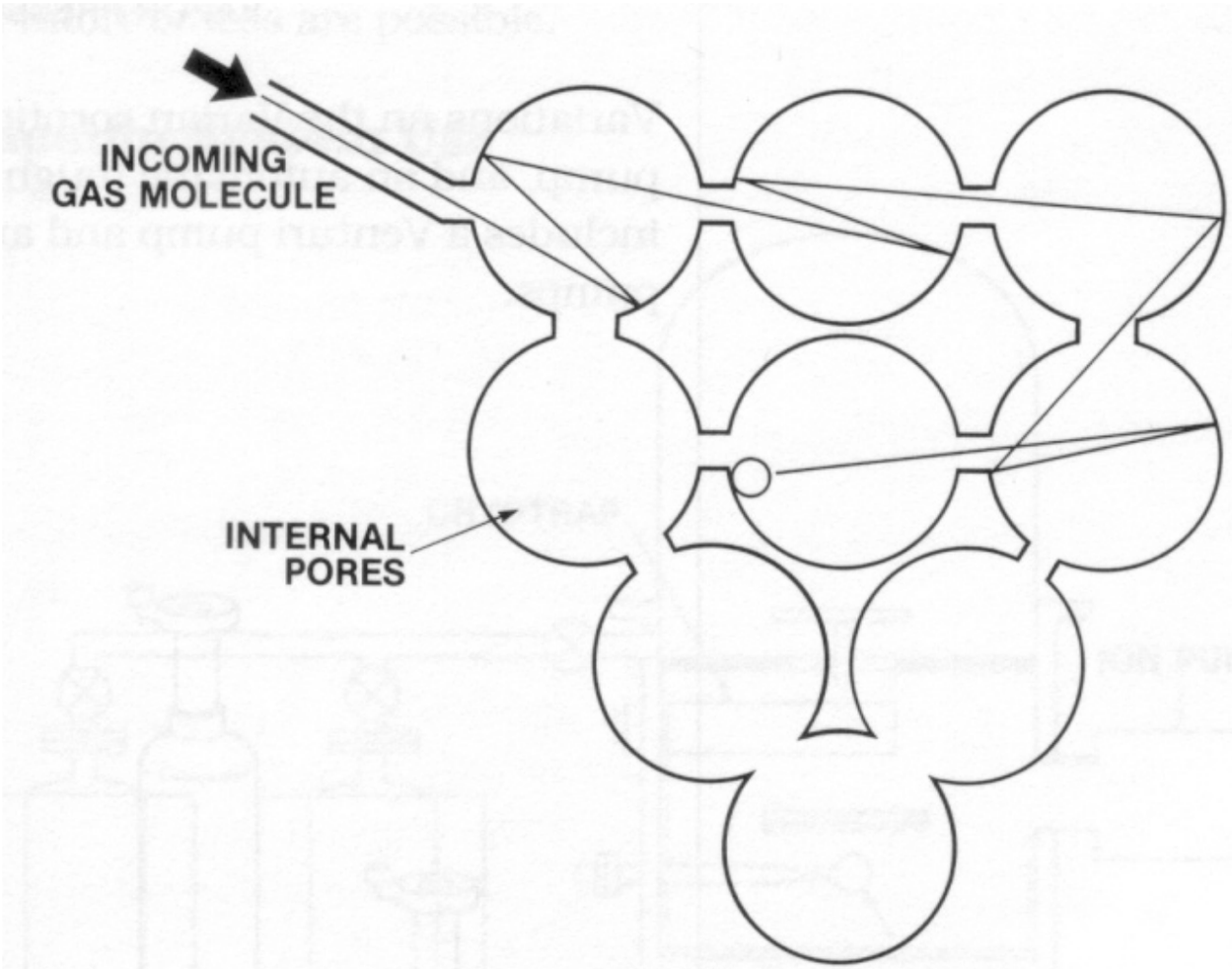


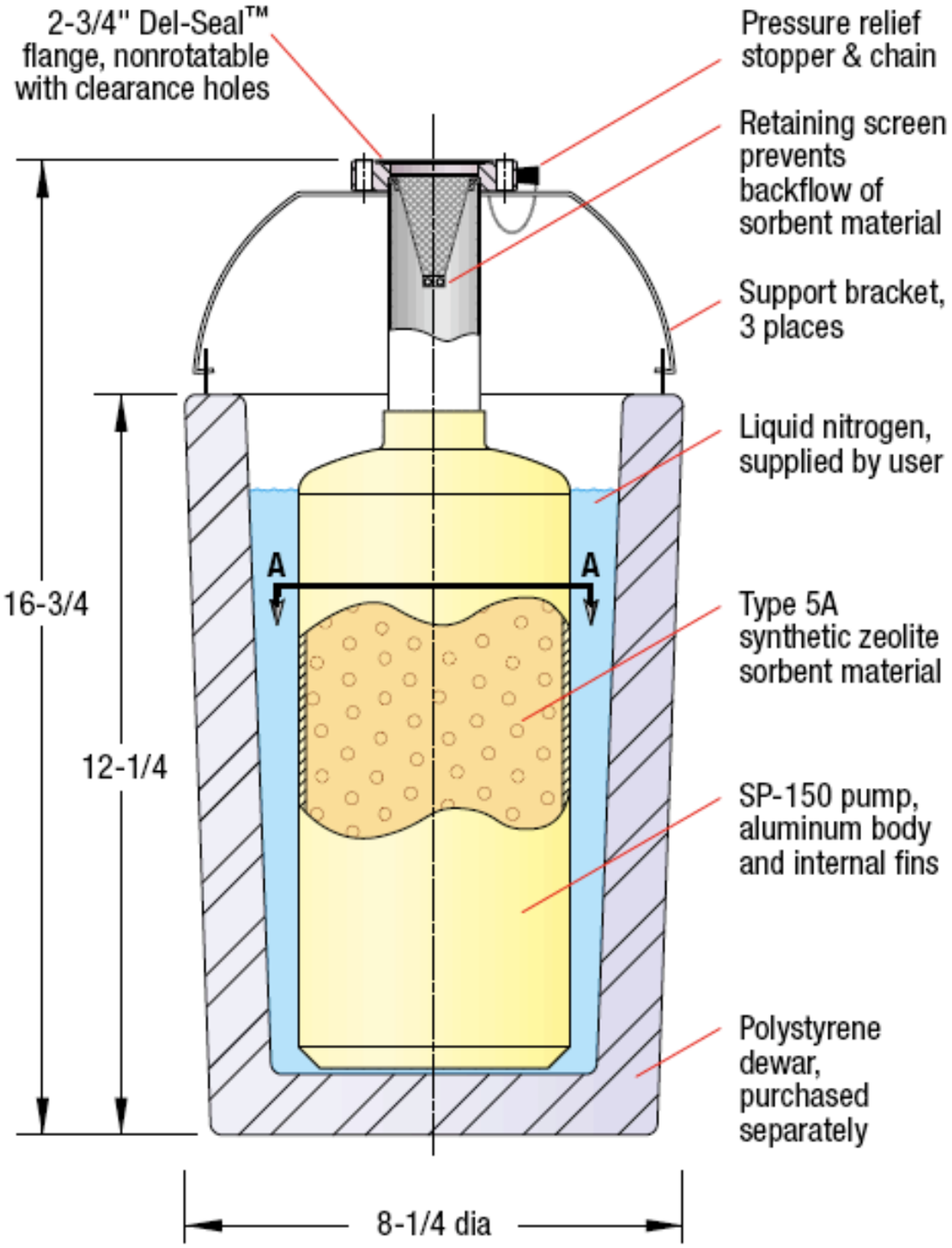
Blower/booster pump





Sorption pumps




2-3/4" Del-Seal™ flange, nonrotatable with clearance holes
Pressure relief stopper & chain
Retaining screen prevents backflow of sorbent material
Support bracket, 3 places
Liquid nitrogen, supplied by user
Type 5A synthetic zeolite sorbent material
SP-150 pump, aluminum body and internal fins
Polystyrene dewar, purchased separately
A
A
16-3/4
12-1/4
8-1/4 dia

Oil Sealed Pumps		
Type	**Advantages**	**Disadvantages**
Rotary Vane	Low ultimate pressure. Low cost Long pump life.	Backstreams oil. Produces hazardous waste.
Rootes Lobe	Very high pumping speed.	Frequent maintenance. Requires a purge gas. Requires a backing pump. Must be absolutely horizontal.
Rotary Piston	High volume. Low cost.	Noise. Vibration Safety Valve.
Dry Roughing Pumps		
Scroll	Clean. Low "dry" ultimate pressure. Easily servicable Quiet. Evolved from air conditioning compressor so technology is well known.	Limited bearing life. Limited scroll life. Permeable to small gases. Not hermetically sealed. Clean applications only.
Diaphragm	Low cost. Quiet. Easily serviced.	Low pumping speed. High ultimate pressure. Frequent service required.
Hook & Claw	No backstreaming. Low ultimate pressure.	Expensive.
Screw Rotor	Low ultimate vacuum. Less maintenance than hook & claw.	Expensive.

Diffusion pumps

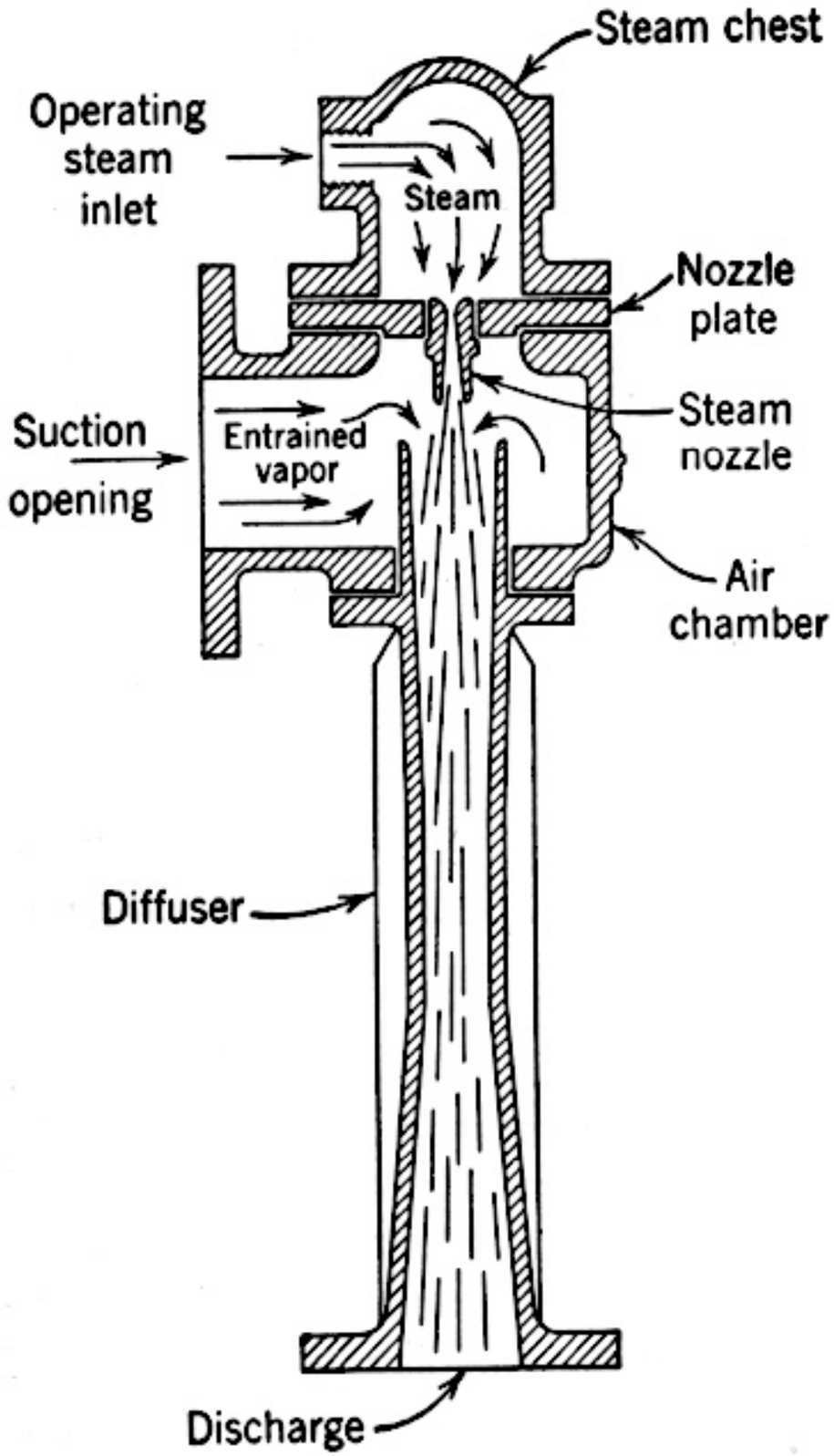
require rough pump backing:
~10^{-3} Tr

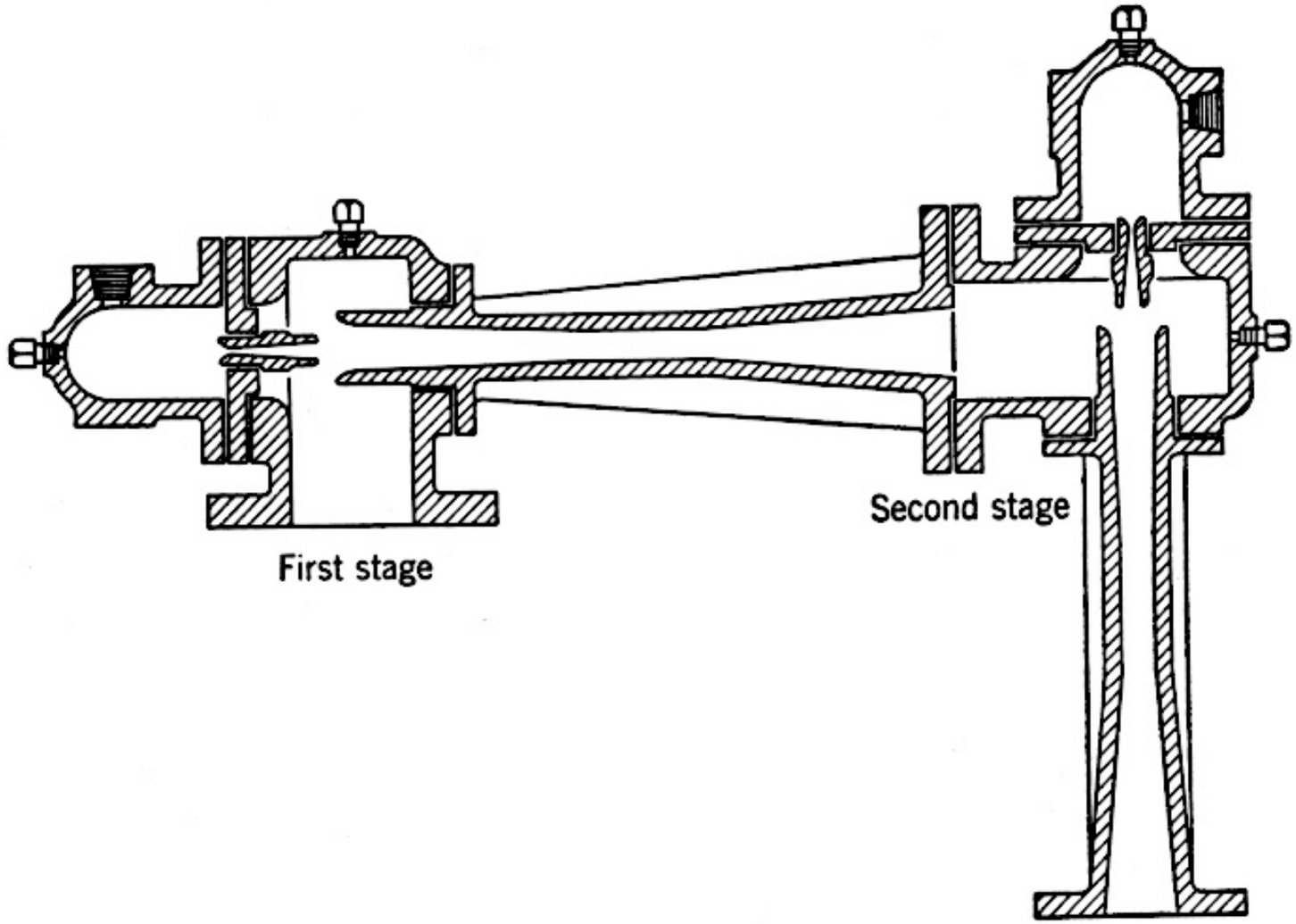
require watercooling

speeds 100-50000 l/s

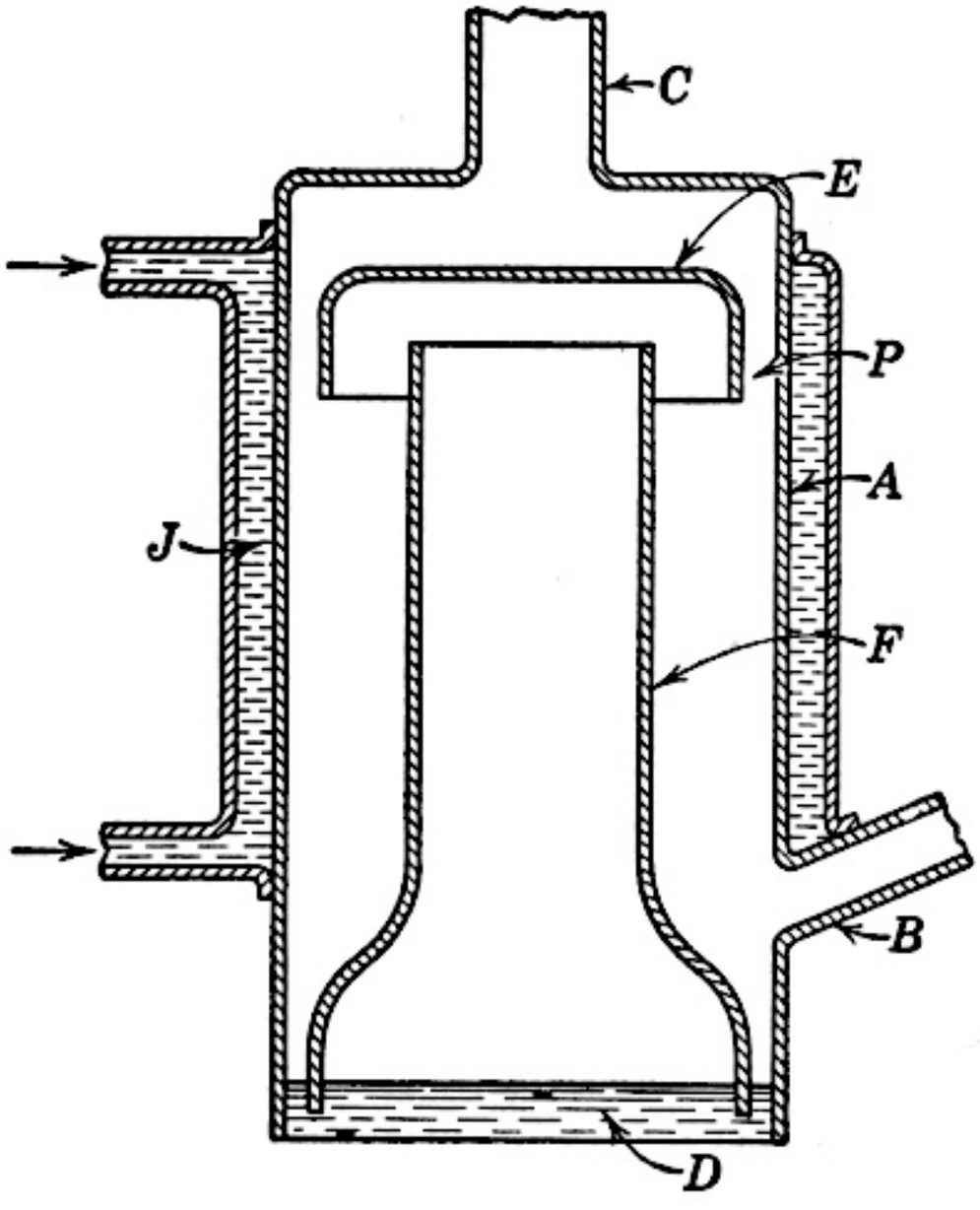
ultimate pressure <10^{-9} Tr

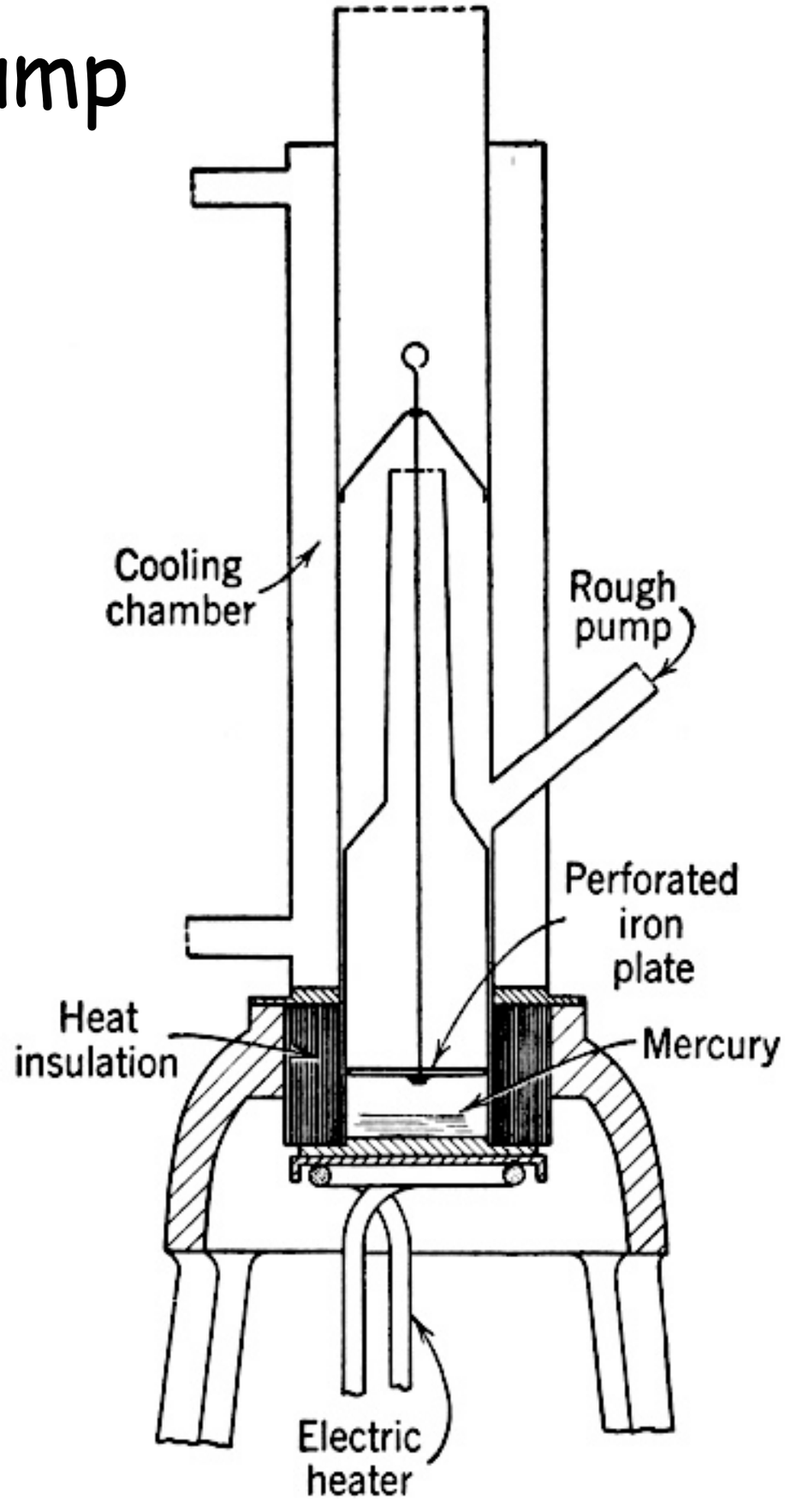
Jet ejector pumps



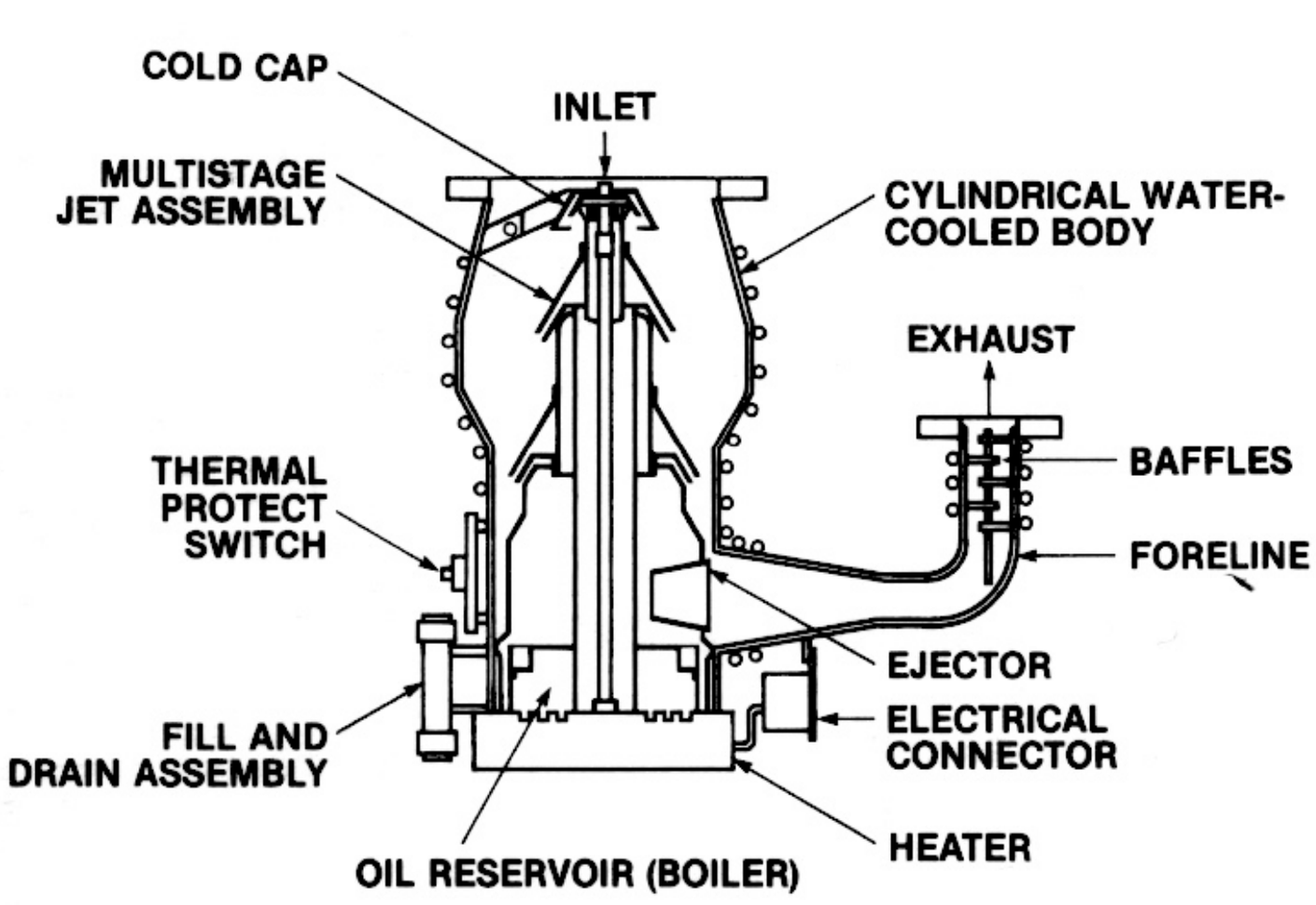


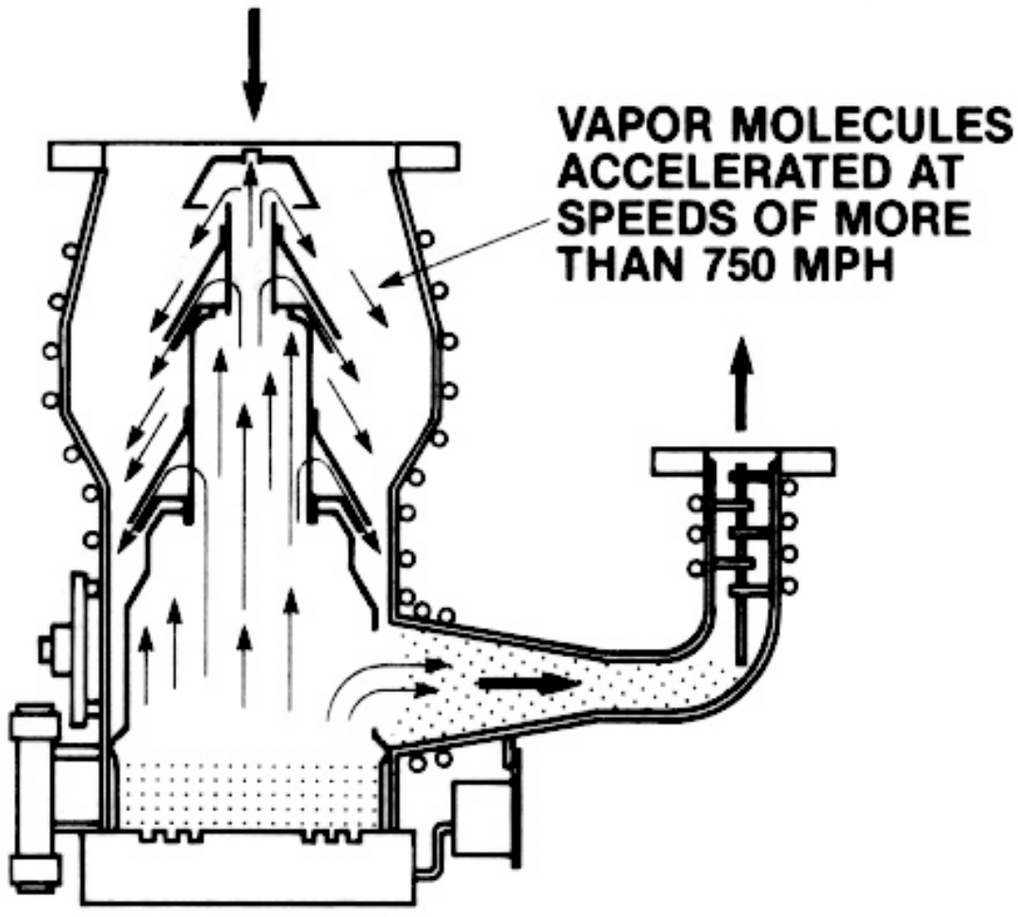
Langmuir condensation pump

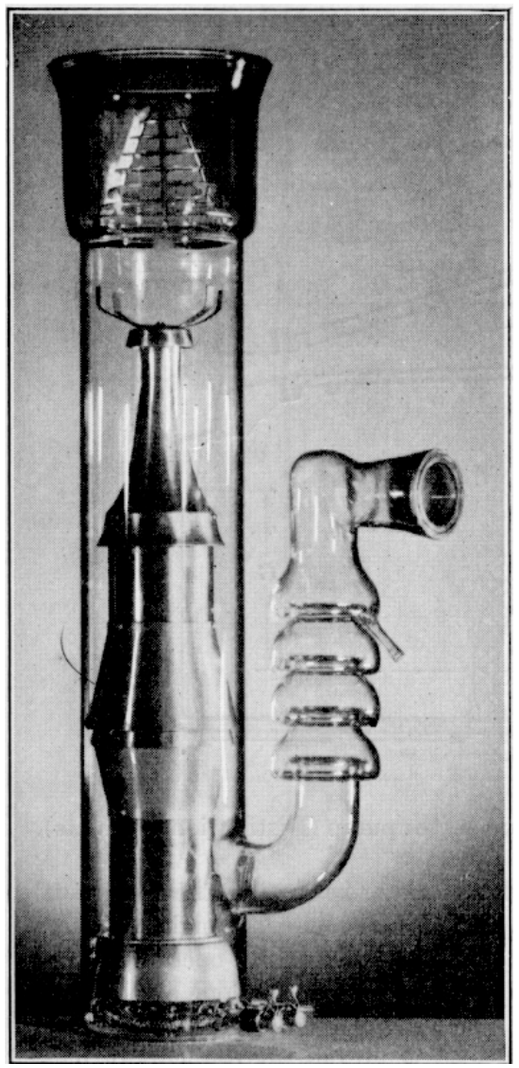


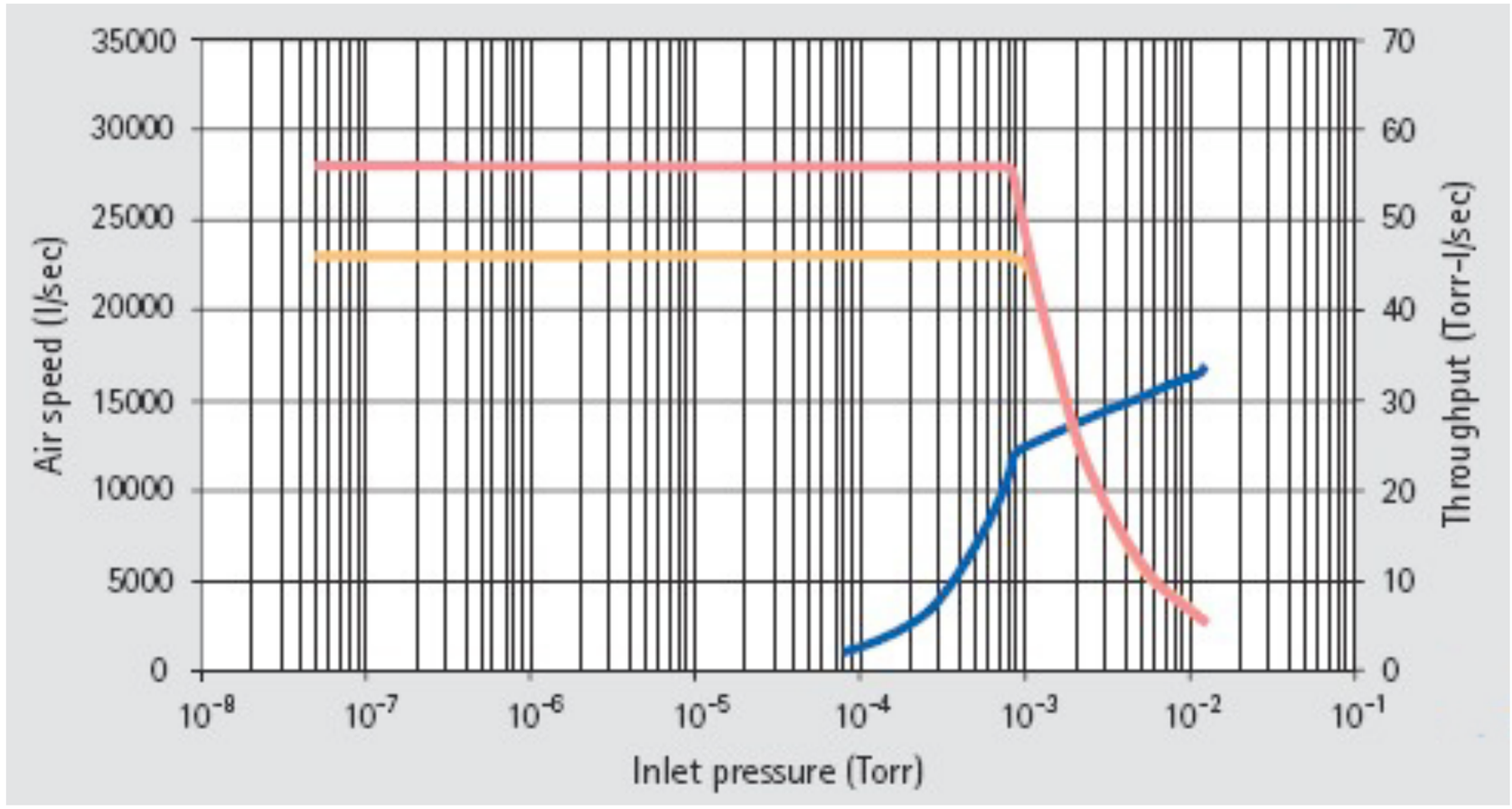


Diffusion pumps (mercury or oil)

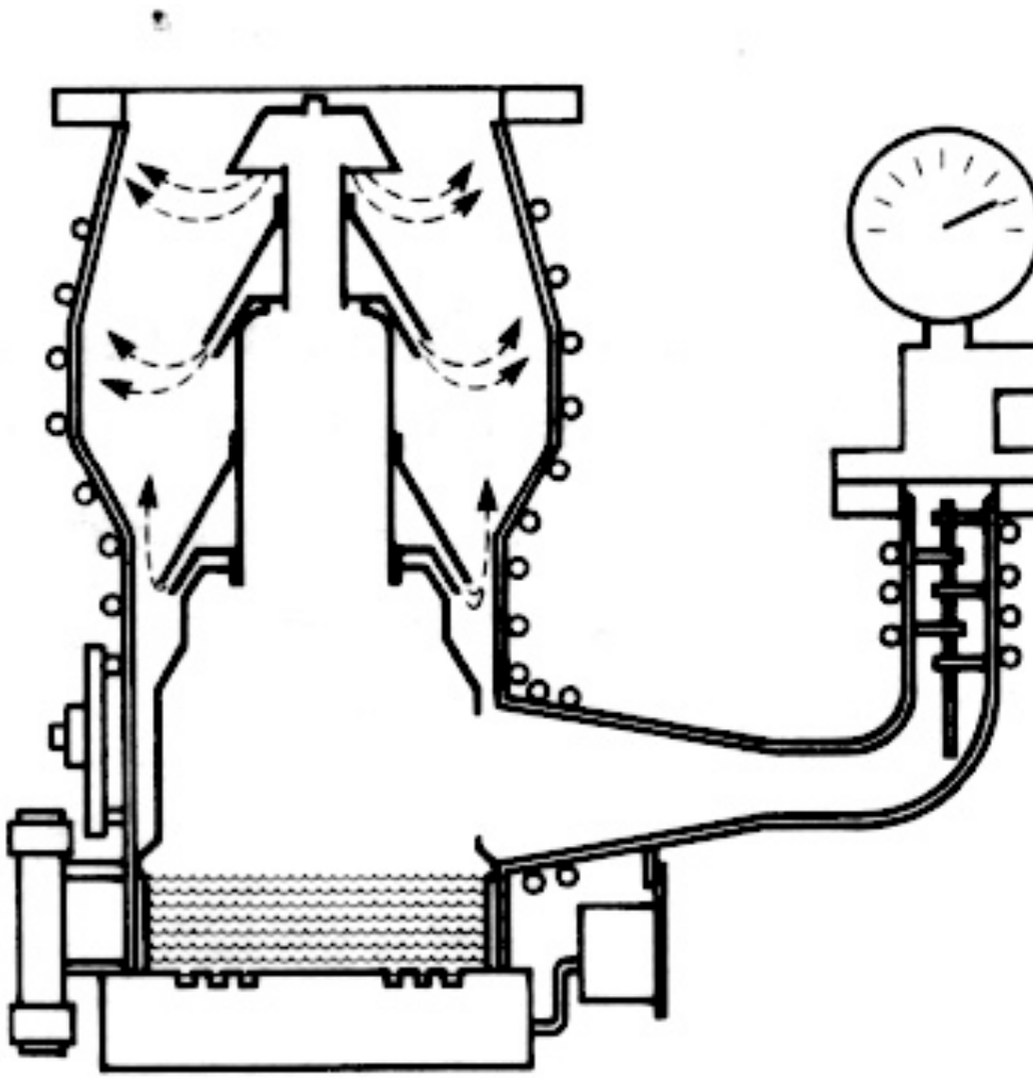


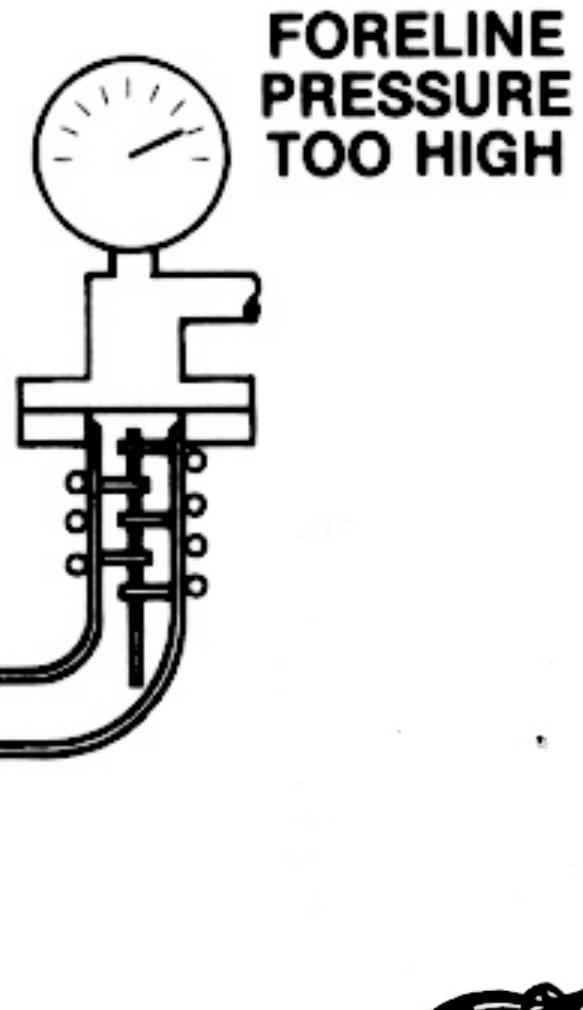





35000
30000
25000
20000
15000
10000
5000
0
Air speed (l/sec)
70
60
50
40
30
20
10
0
Throughput (Torr-l/sec)
10^{-8}
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
Inlet pressure (Torr)

watch that roughing pump and cooling water ...





Molecular drag/turbomolecular pumps

require rough pump backing:

10^{-1} Tr for molecular

10^{-4} Tr for turbo

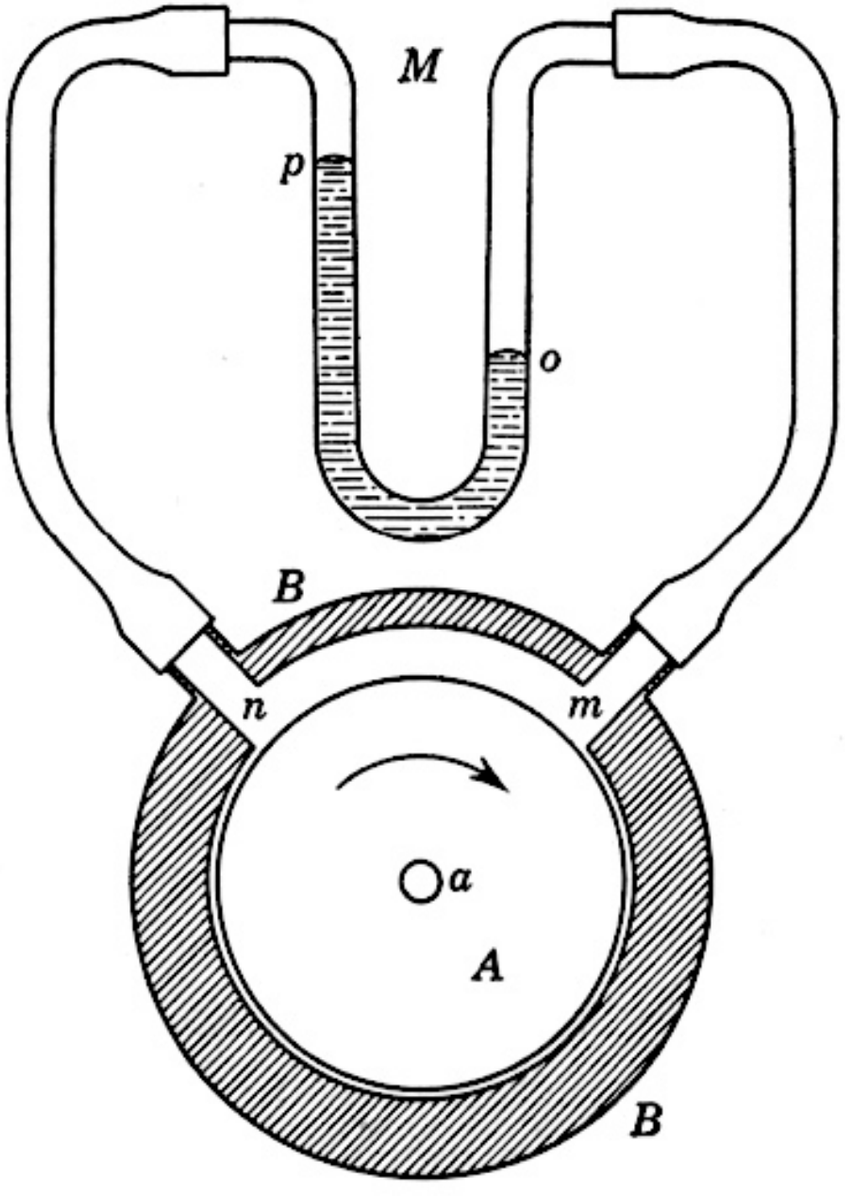
10^{-2} Tr for turbomolecular

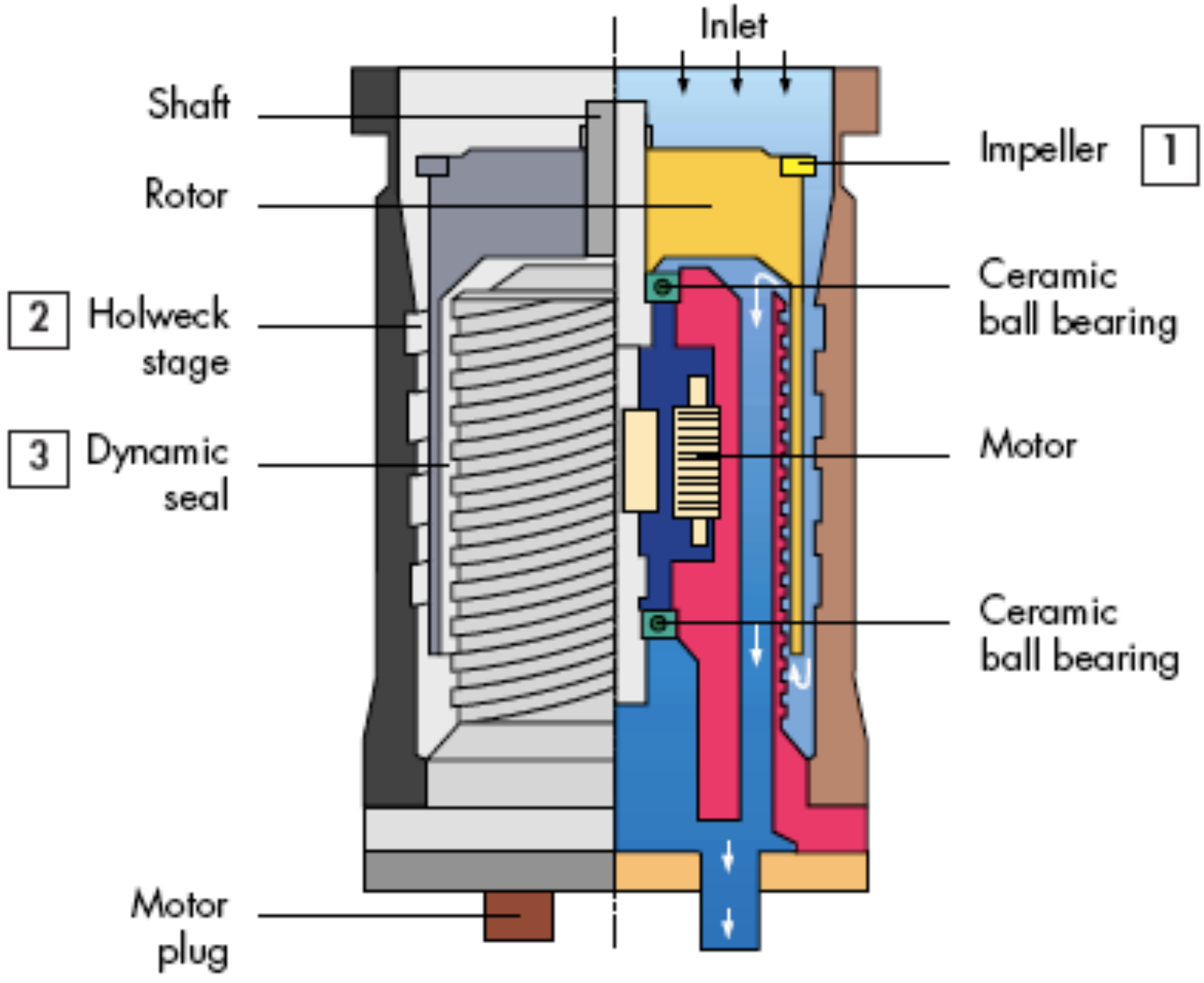
speeds 50-5000 l/s

ultimate pressure $<10^{-11}$ Tr

compression ratio ~ 10^{9}

Molecular drag pump





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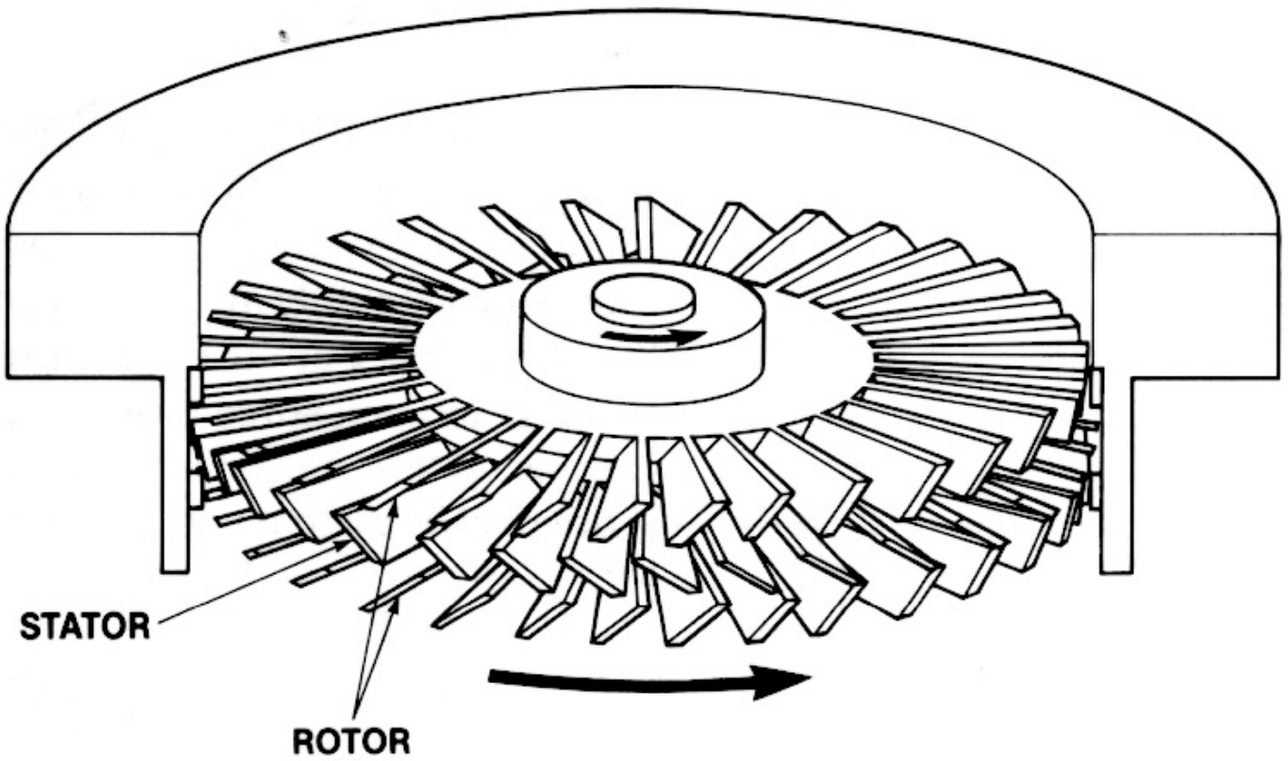
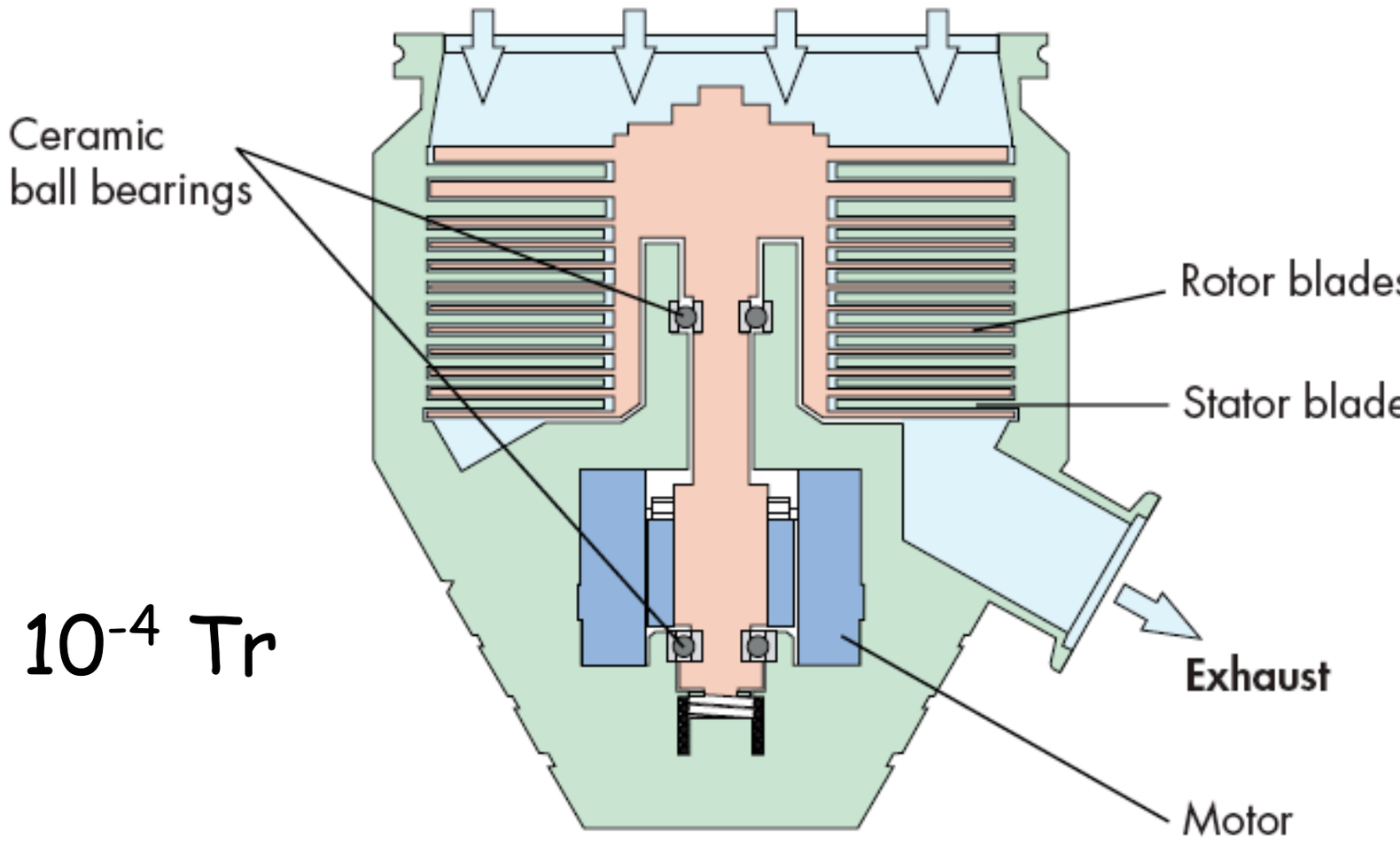
rough pump backing ~ 10^{-1} Tr

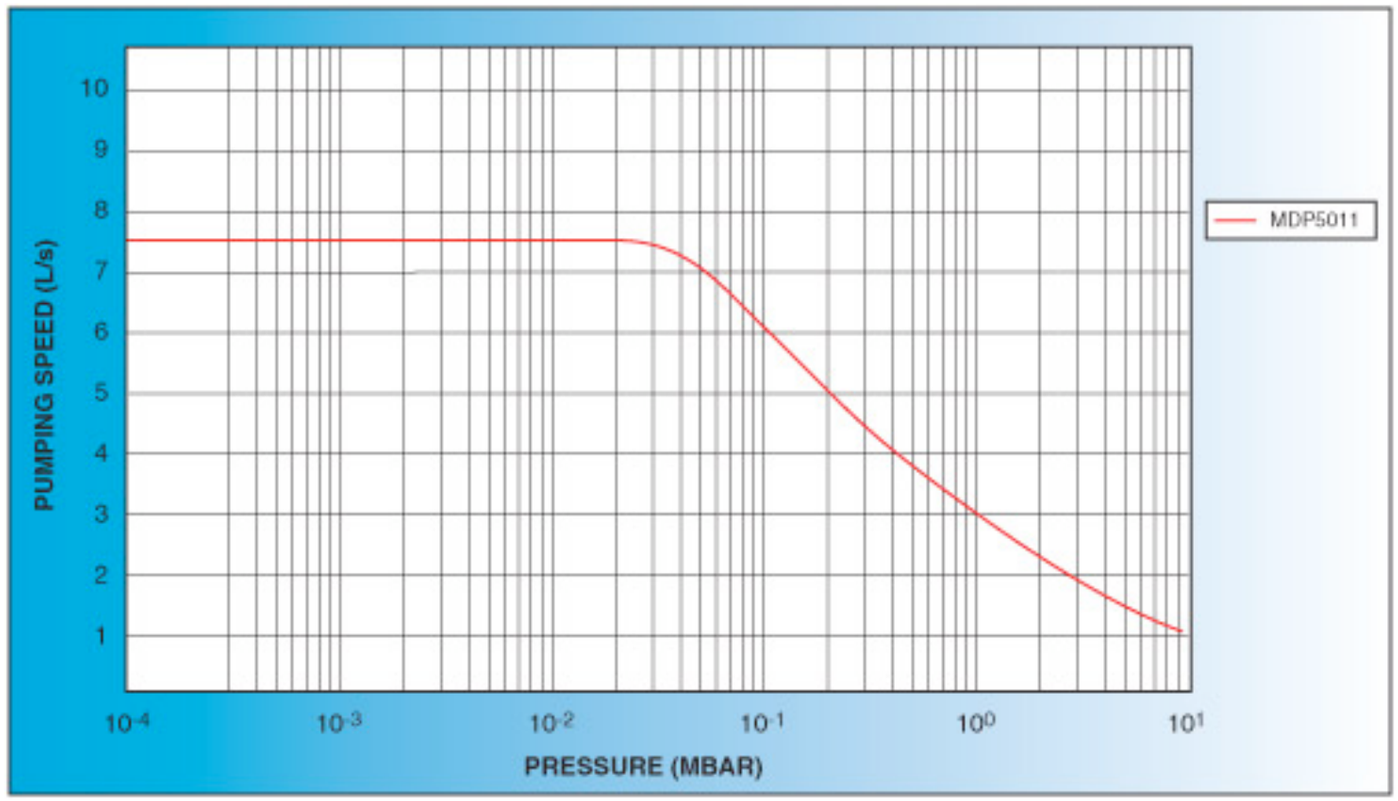
Turbo pump



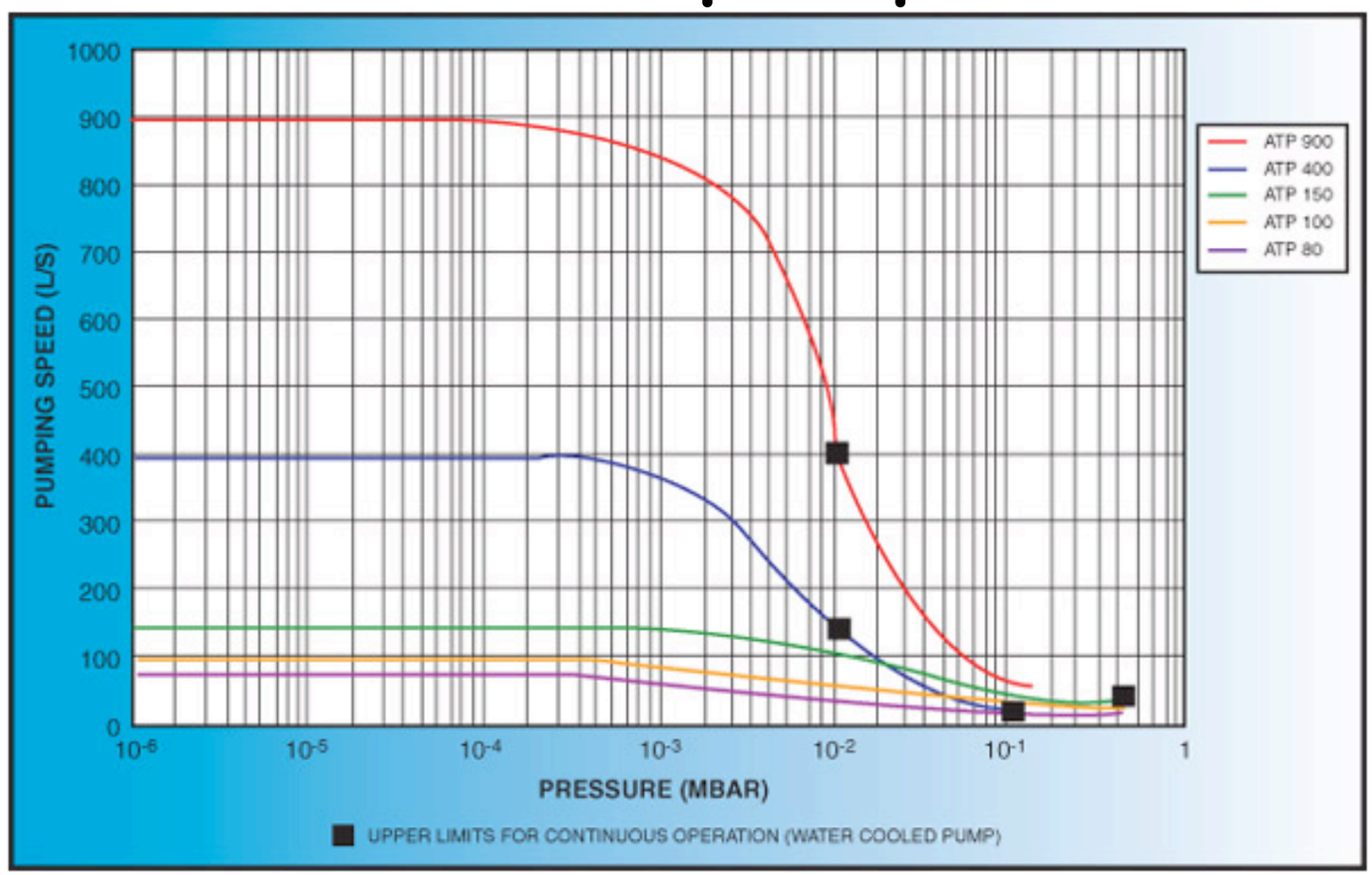


rough pump backing ~ 10^{-4} Tr

Molecular drag pump



Turbo pump



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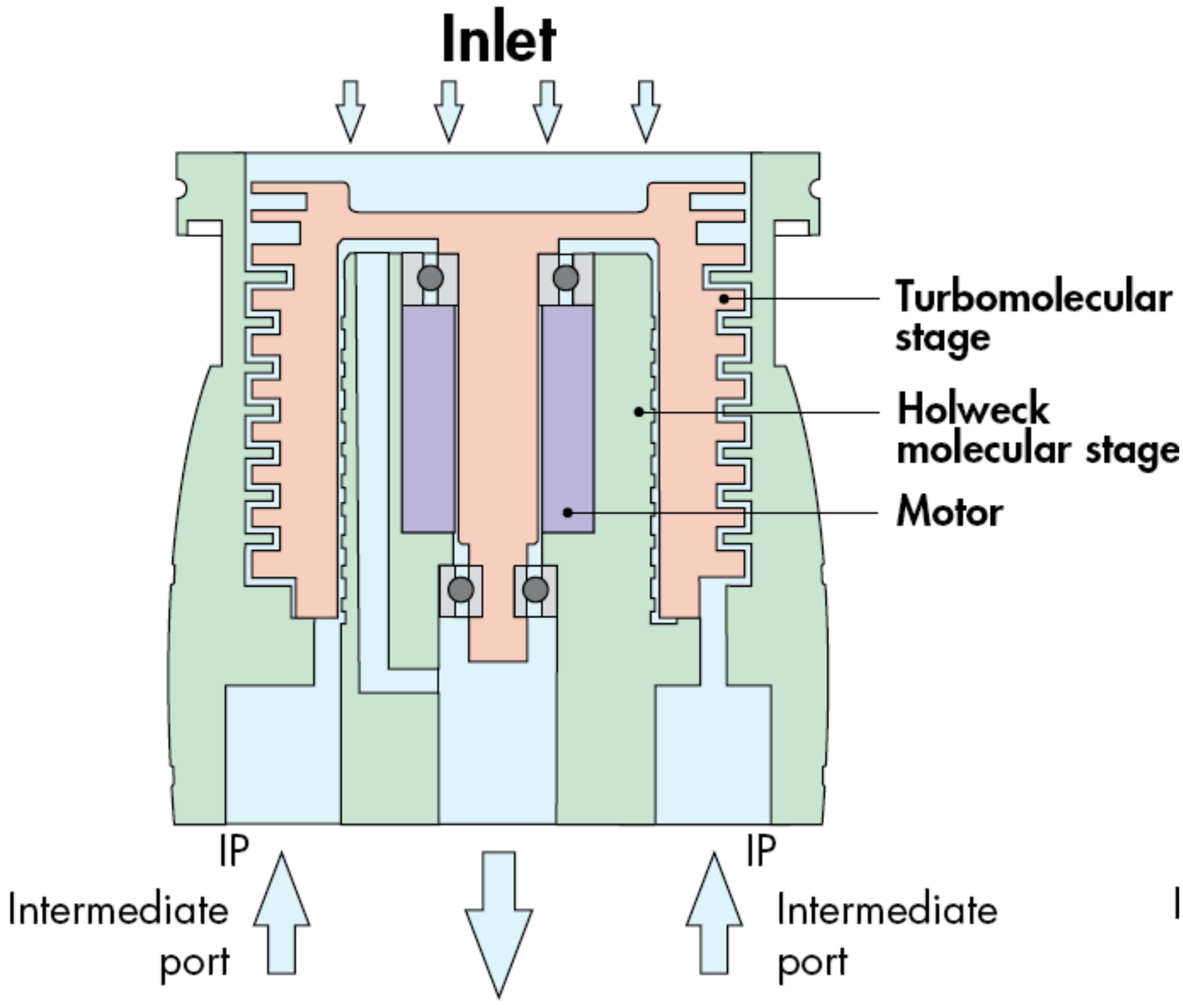
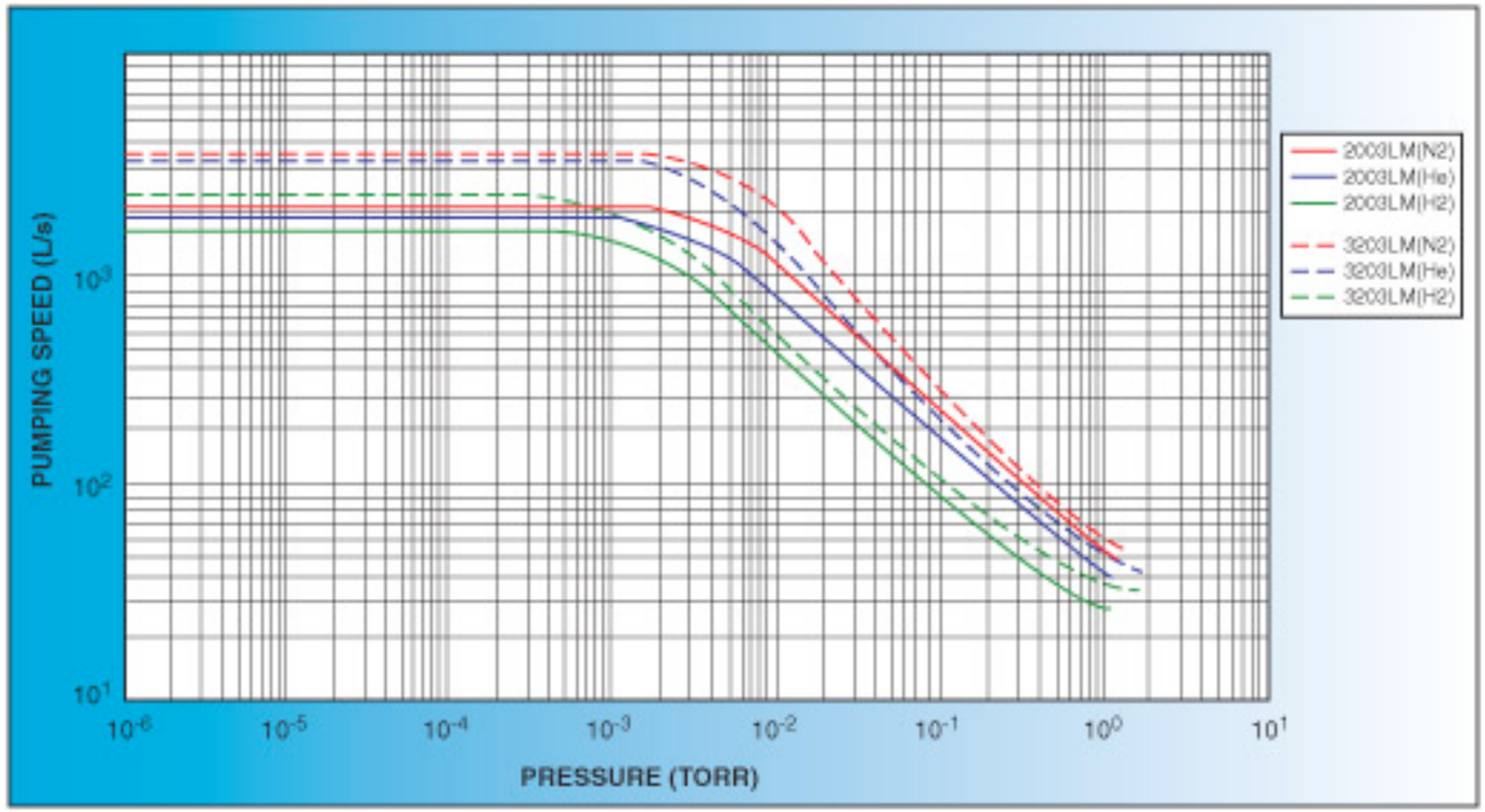
Turbomolecular pump

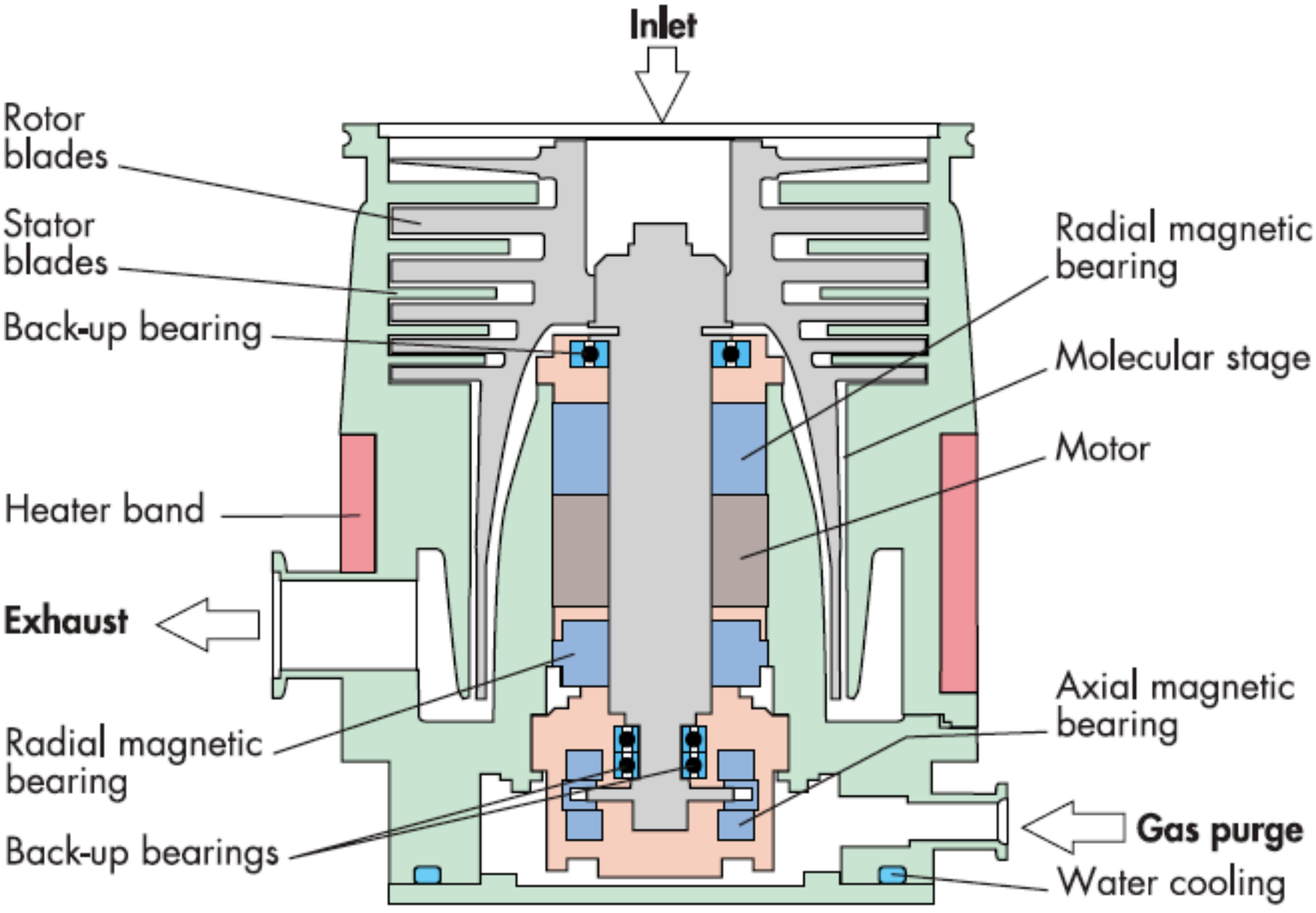


rough pump backing ~ 10^{-2} Tr

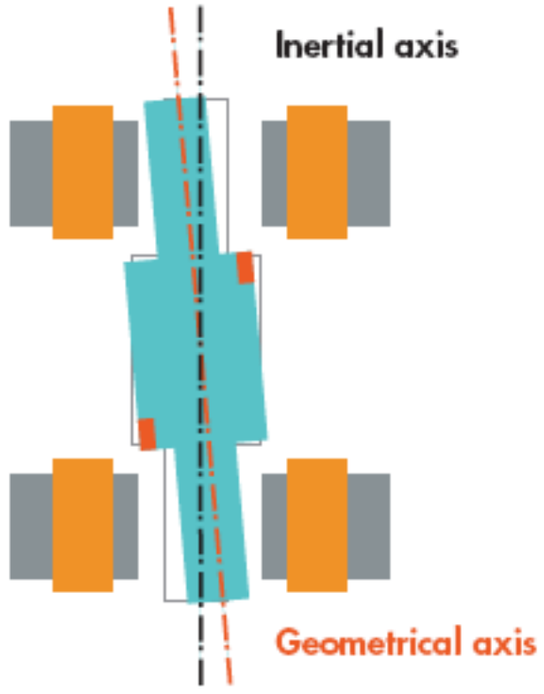
Turbomolecular pumps



Maglev turbomolecular pump



ATH-M cross section



Ion pumps

no need for continuous rough pumping

start-up pressure < 10^{-4} Tr

speeds 50-5000 l/s

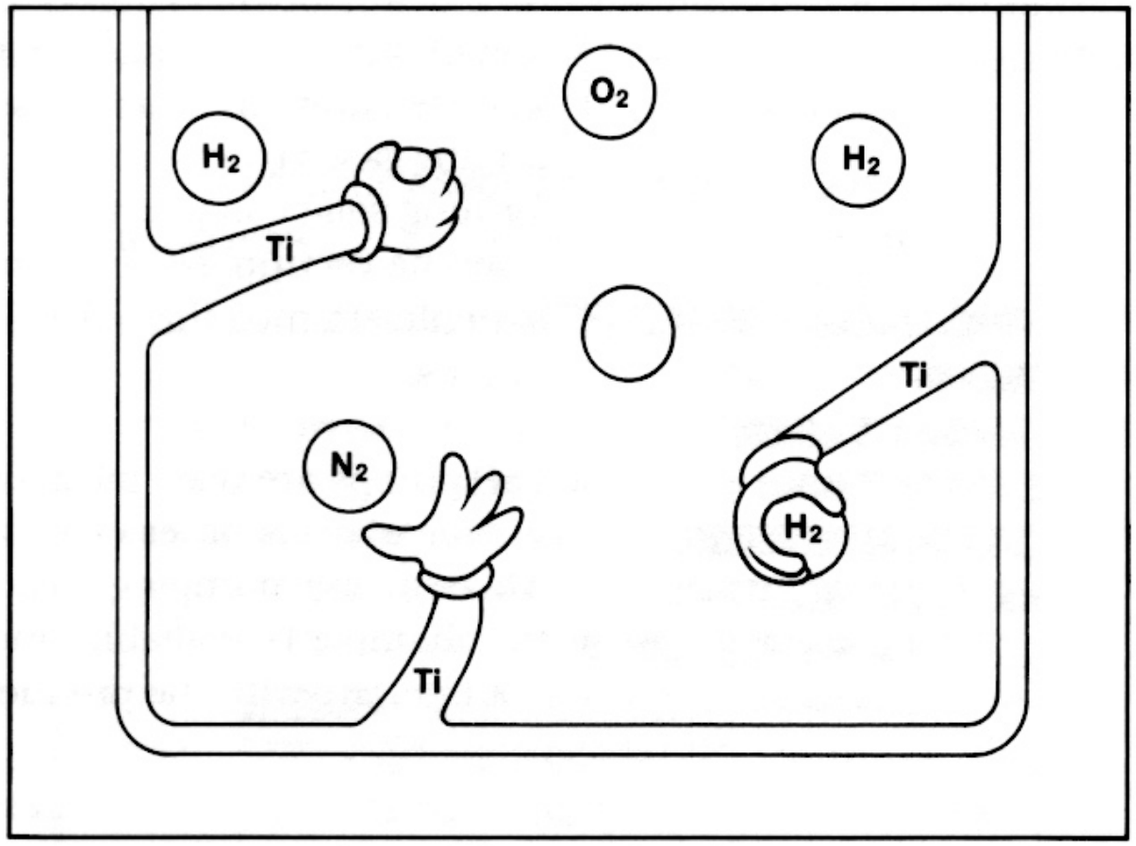
ultimate pressure <10^{-11} Tr

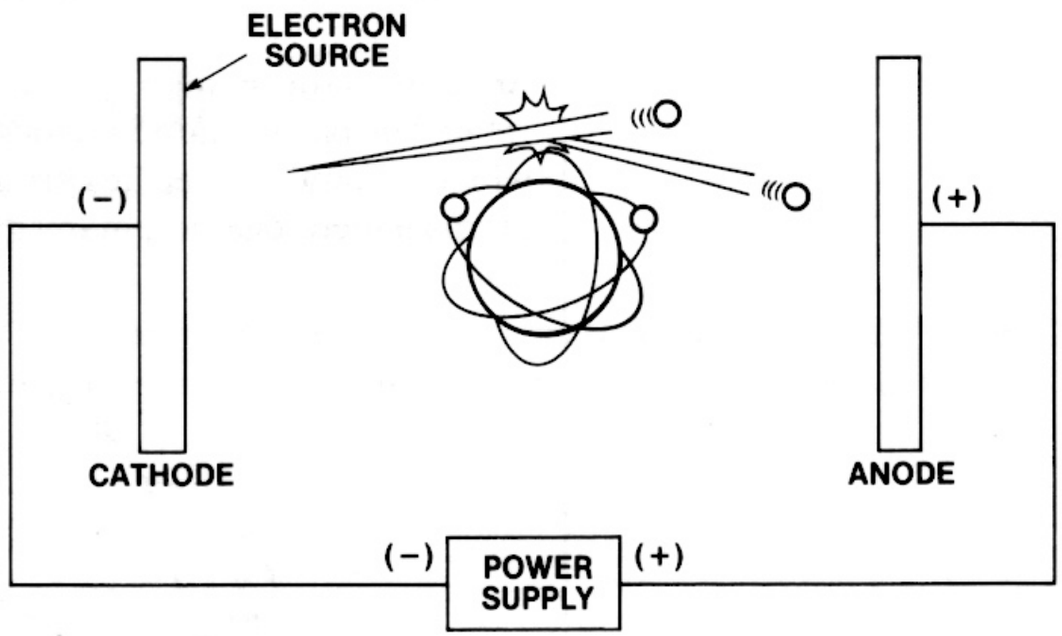
cannot handle continuous gas flow

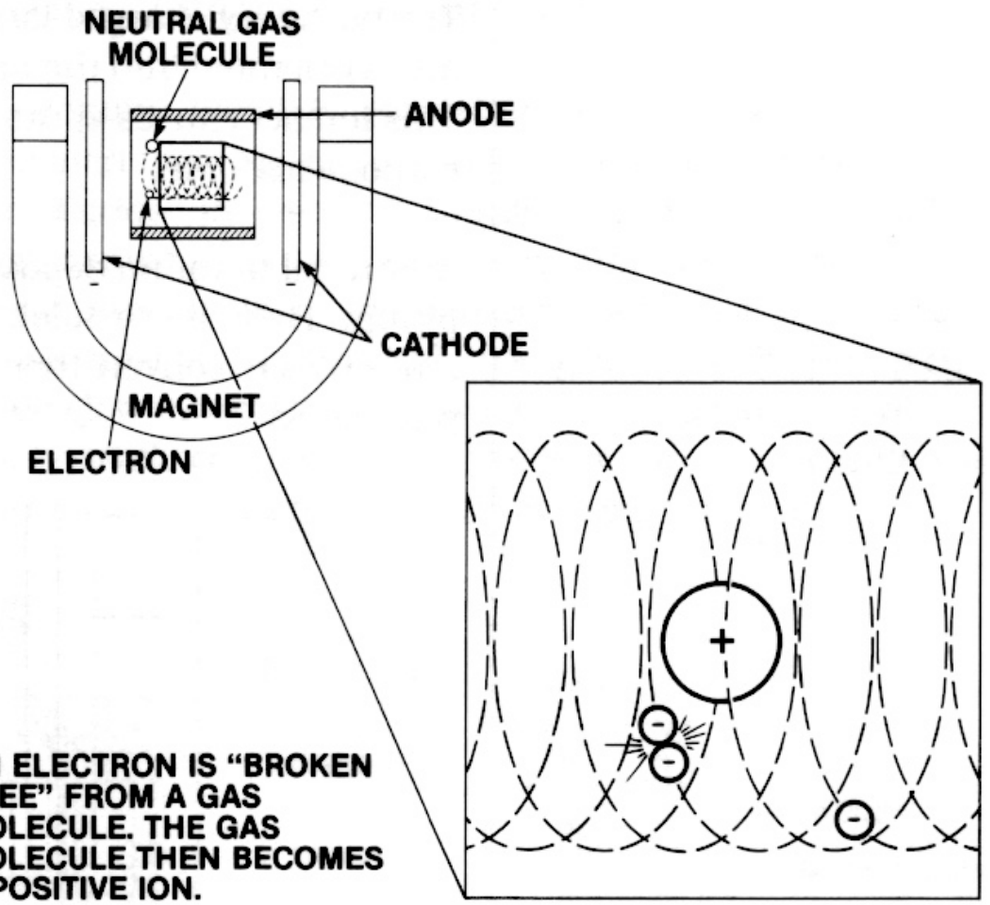
lifetime ~50,000 hrs at 10^{-6} Tr

poor performance for nobel gases (burping)

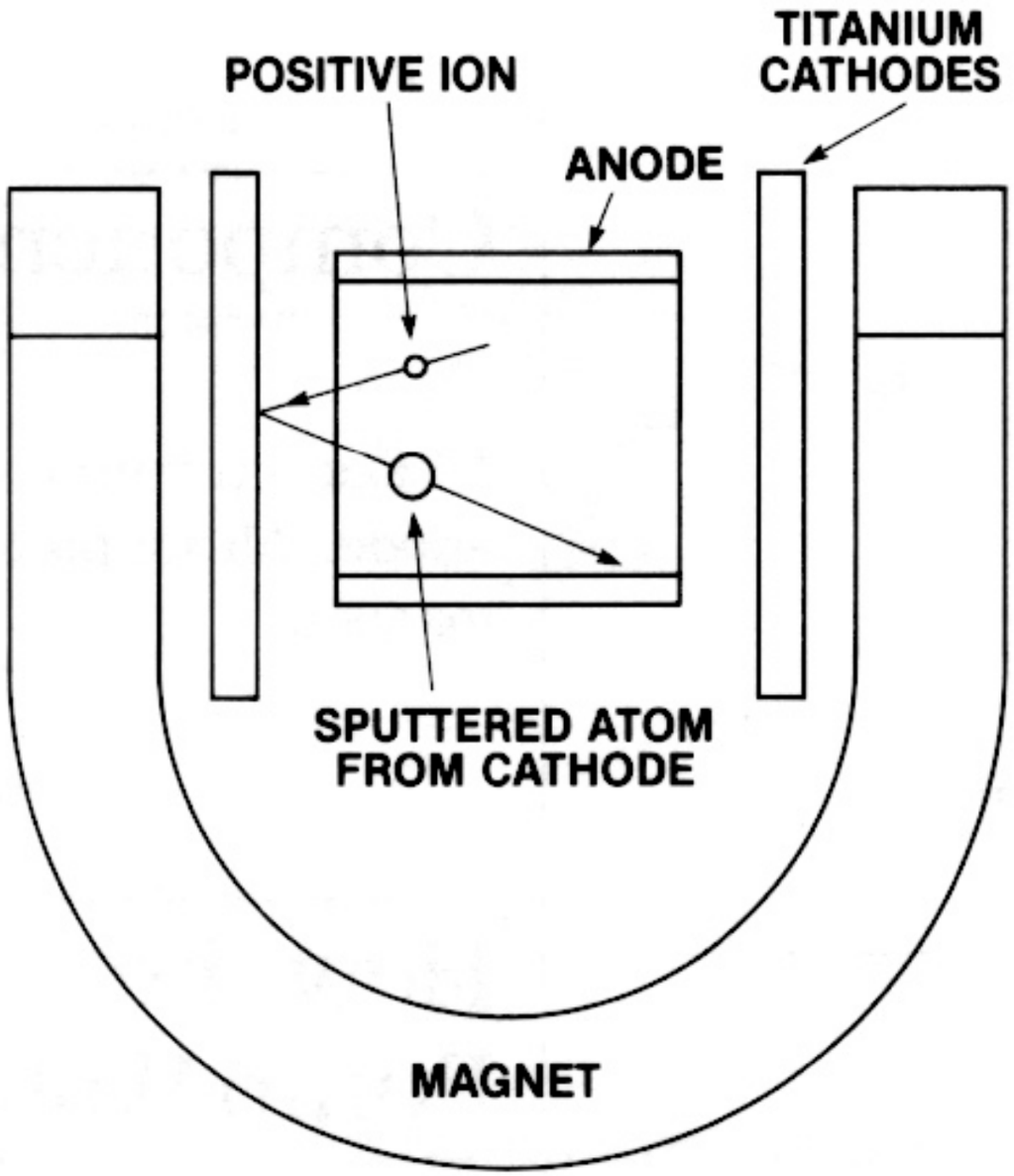
super quiet, little maintenance

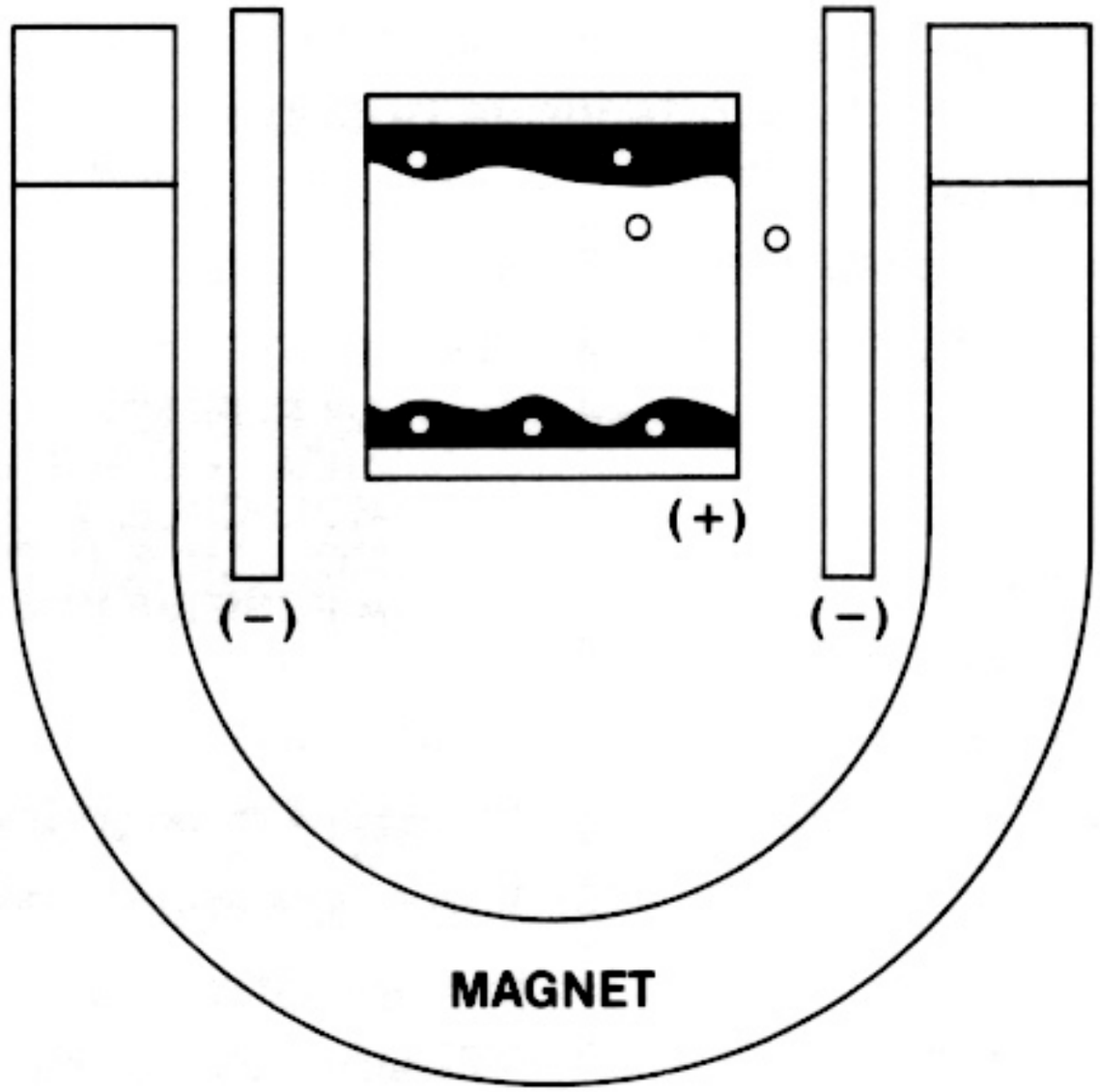




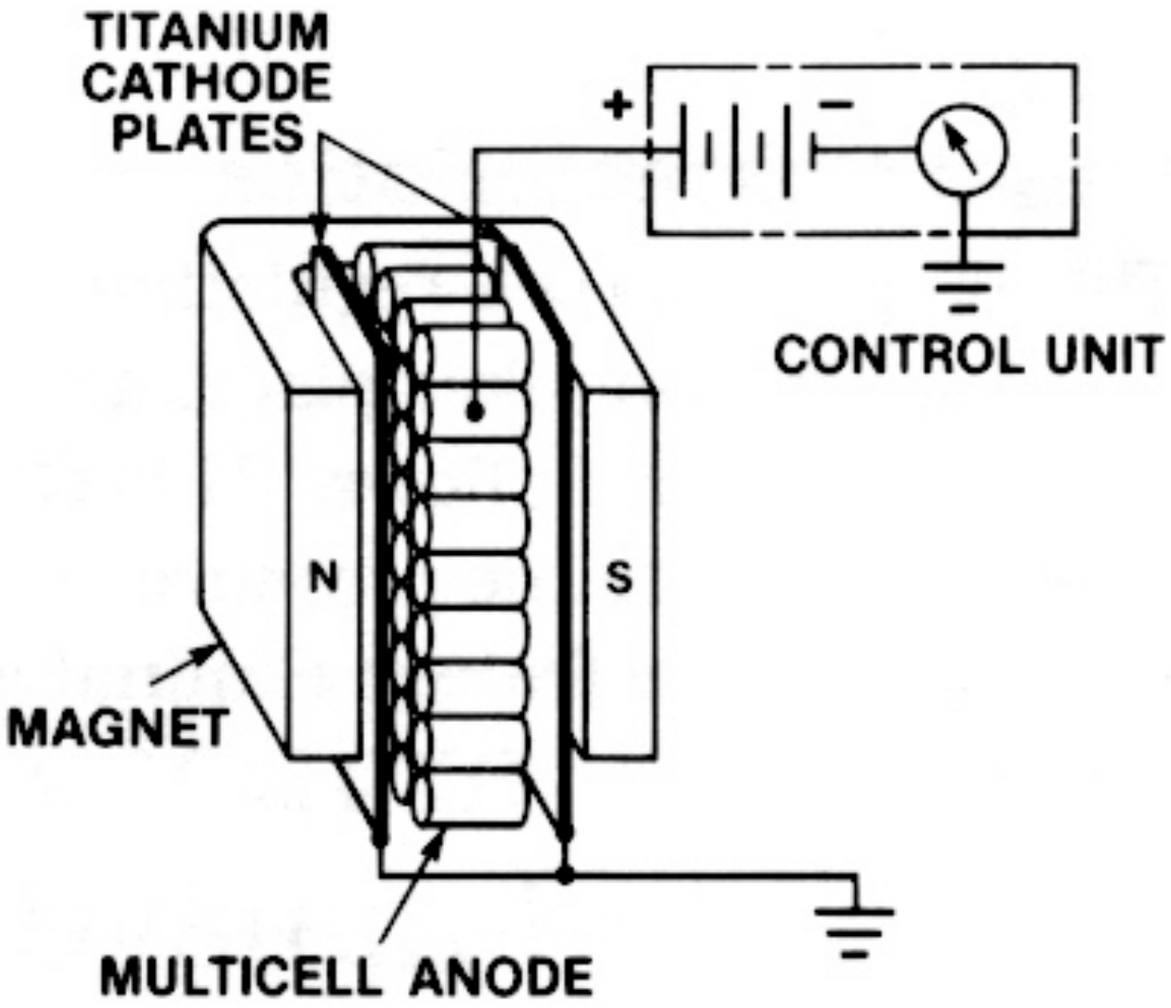


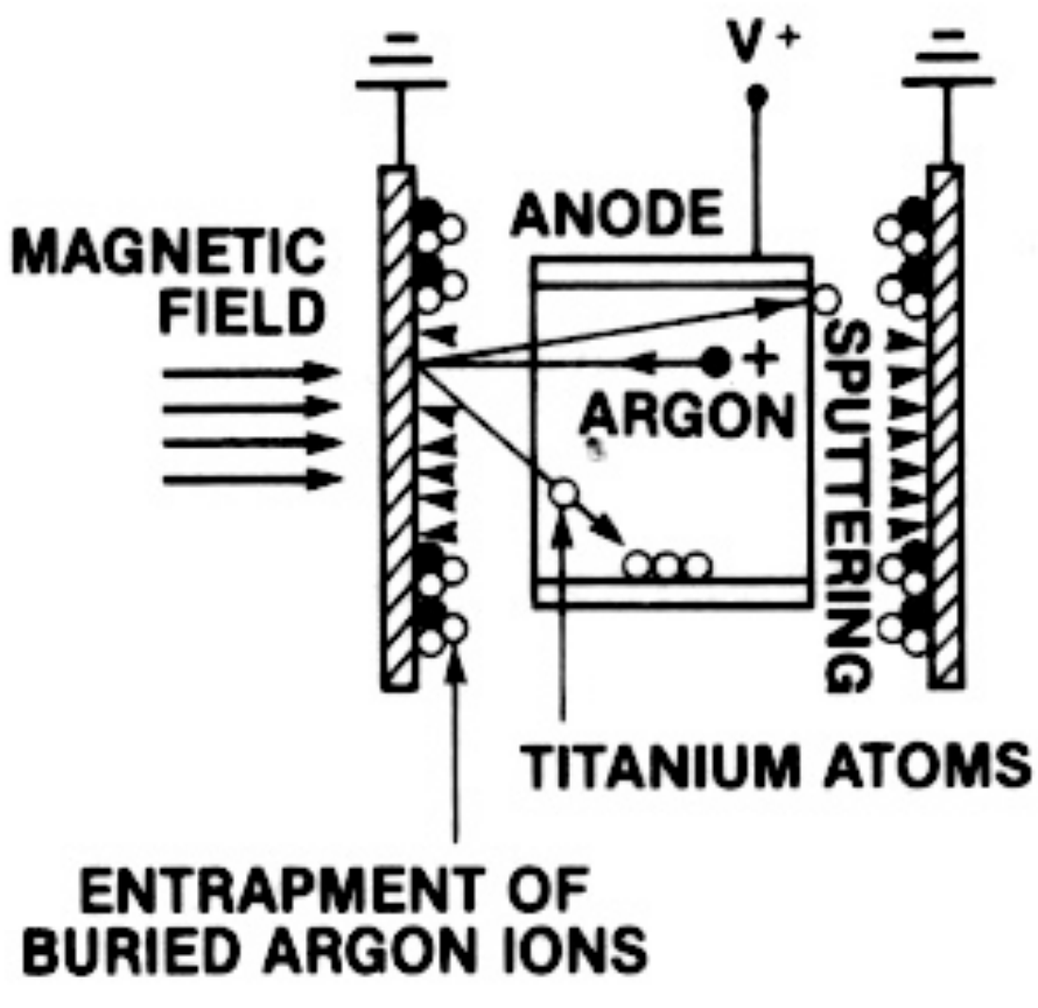
AN ELECTRON IS "BROKEN FREE" FROM A GAS MOLECULE. THE GAS MOLECULE THEN BECOMES A POSITIVE ION.


POSITIVE ION
TITANIUM CATHODES
ANODE
SPUTTERED ATOM FROM CATHODE
MAGNET

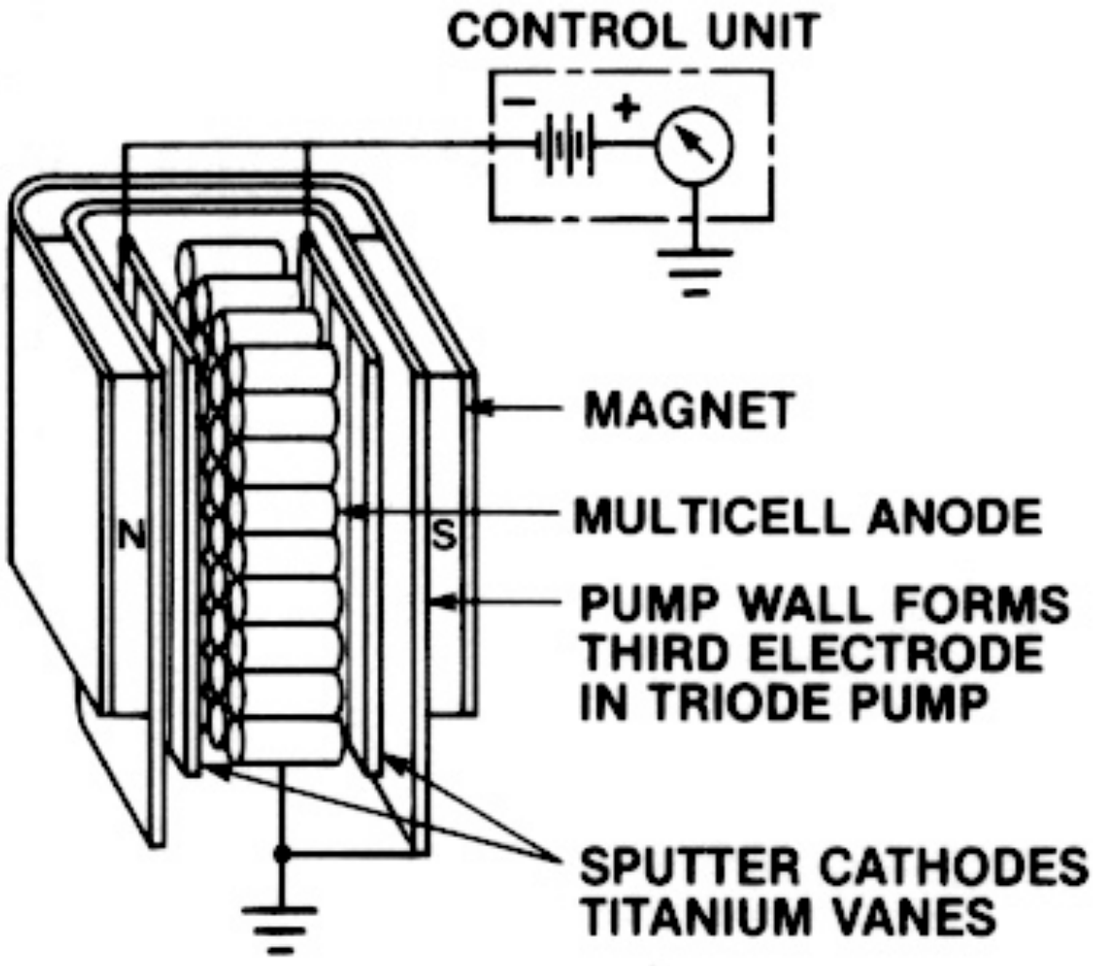

(+)
(−)
(−)
MAGNET

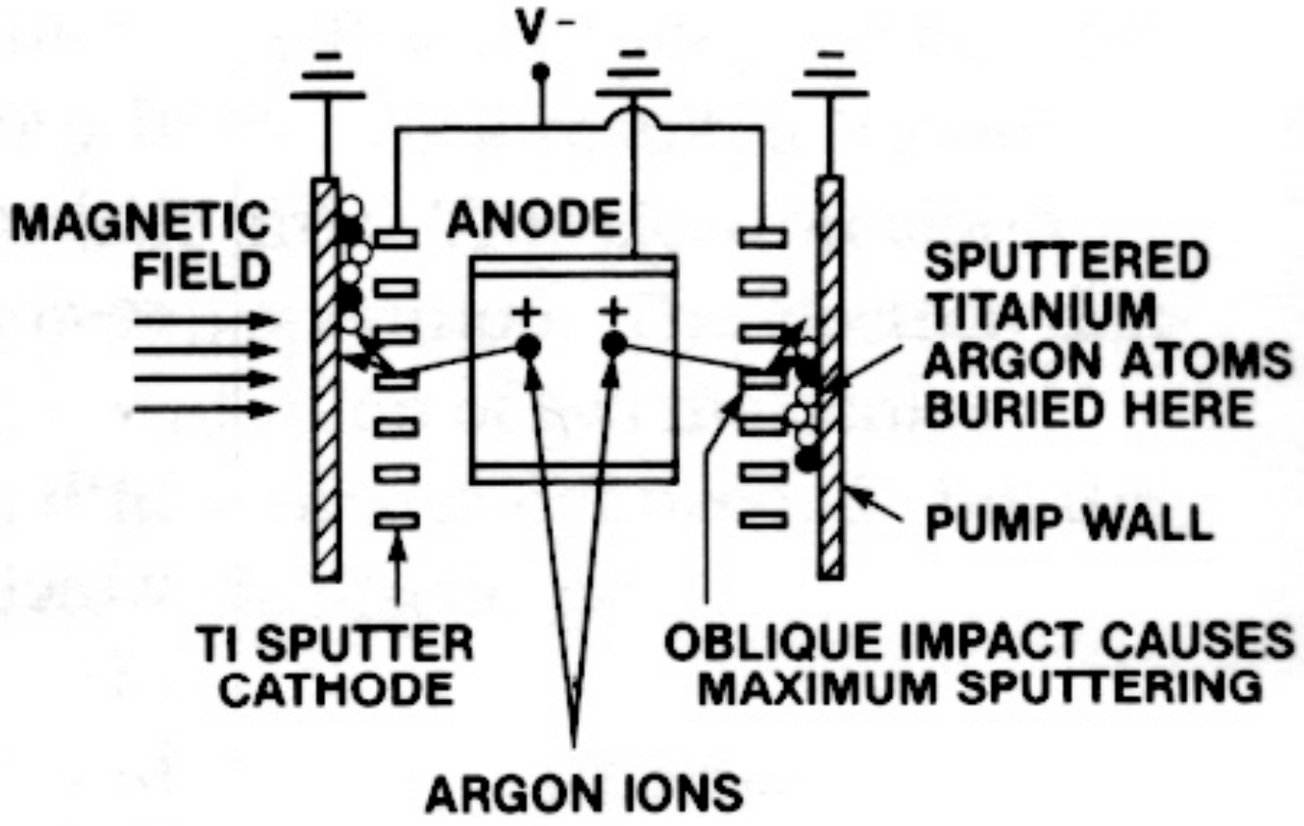
Diode configuration



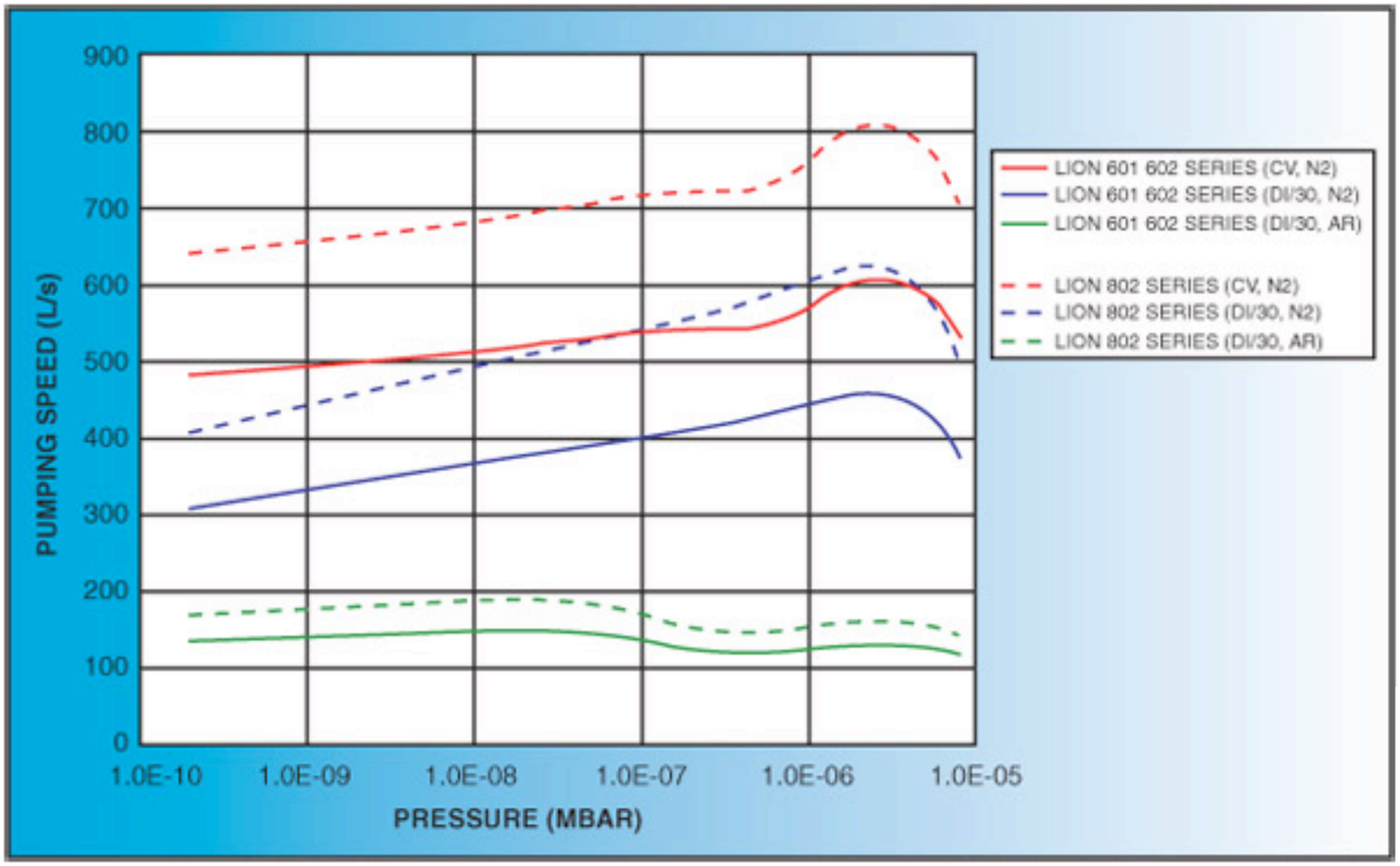


Triode configuration





improved performance for nobel gases and gas load



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Titanium sublimation pumps (TSP)

no need for continuous rough pumping

start-up pressure < 10^{-9} Tr

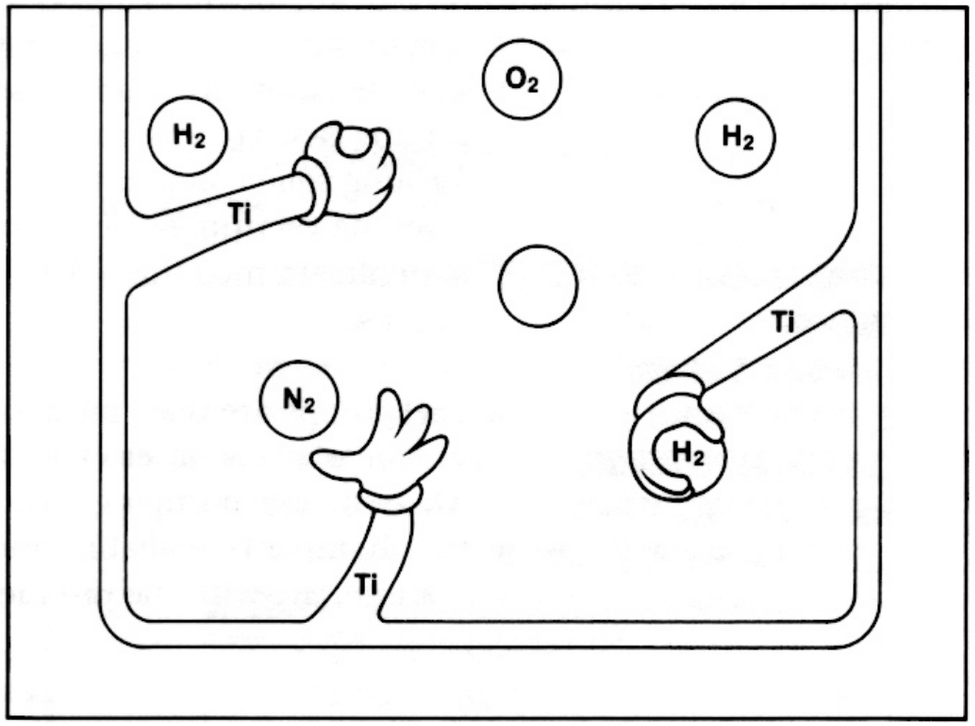
speeds ~1000 l/s

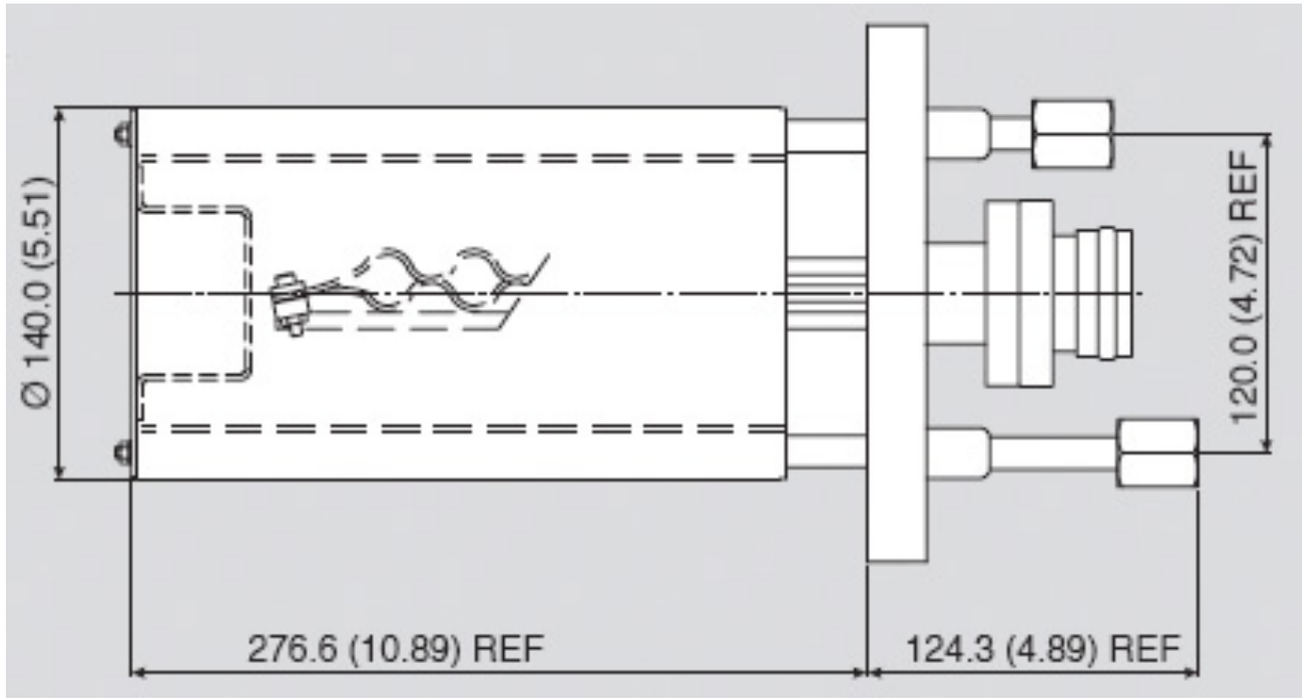
ultimate pressure <10^{-12} Tr

cannot handle continuous gas flow

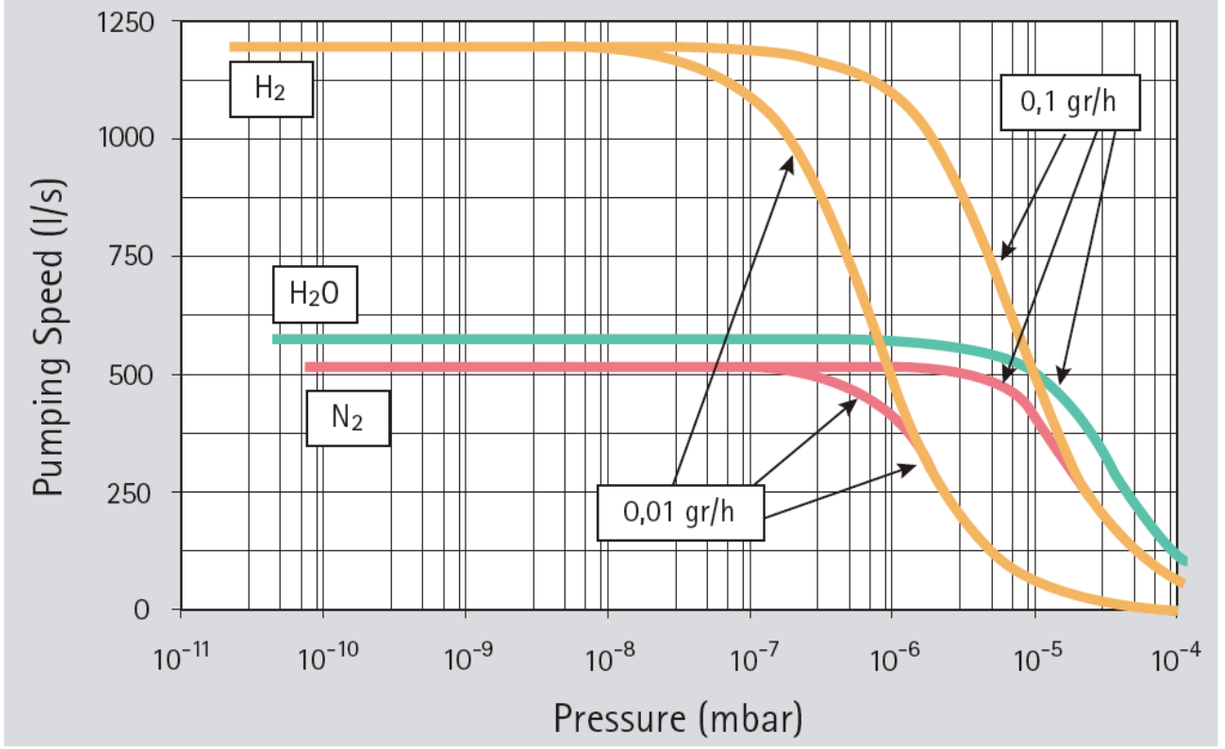
lifetime ~weeks at 10^{-11} Tr

super quiet, little maintenance





Pumping Speed vs Pressure at different evaporation rates



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Cryo pumps

no need for continuous rough pumping

start-up pressure ~ 10^{-4} Tr

speeds 2000-50000 l/s

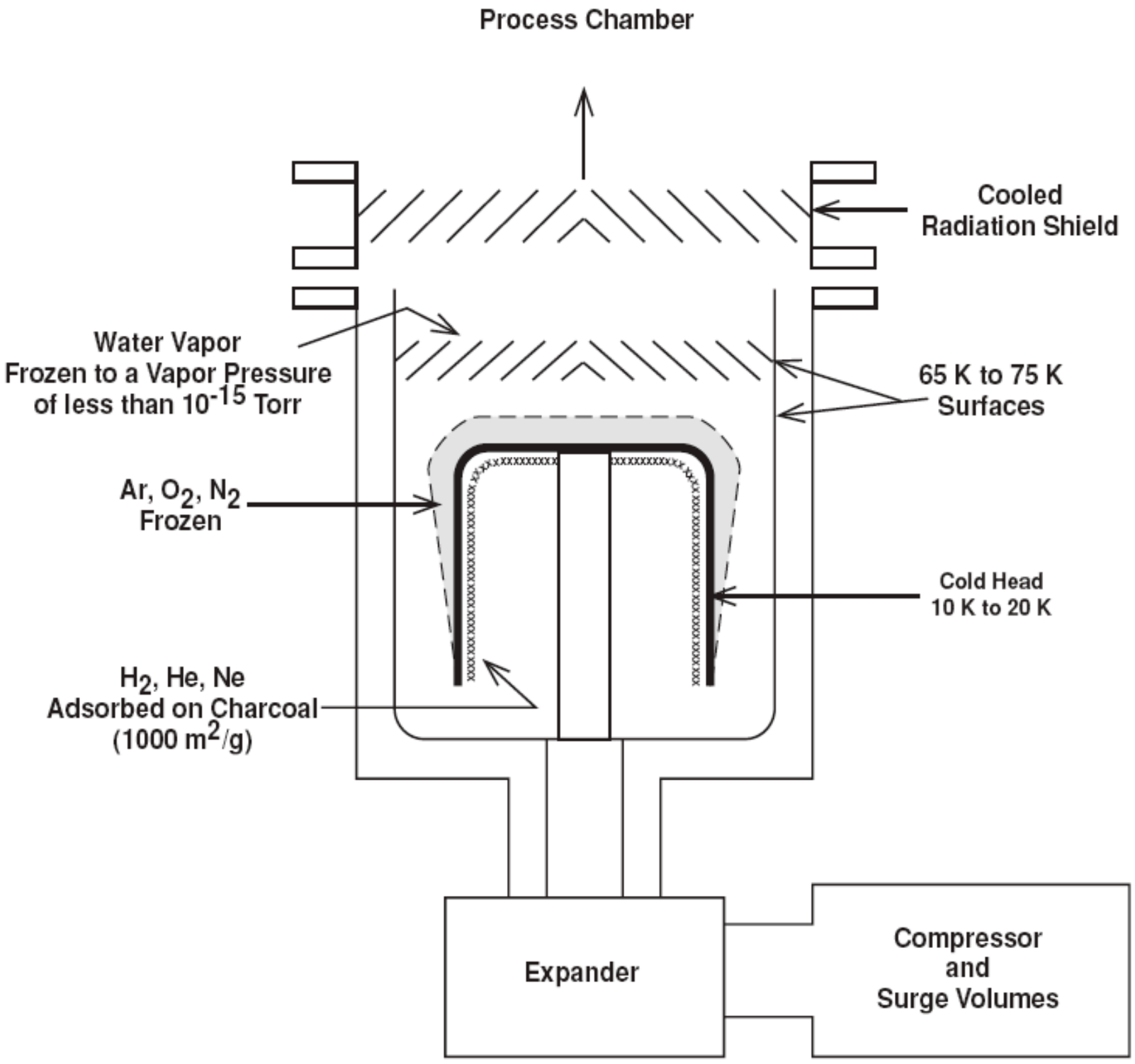
ultimate pressure <10^{-11} Tr

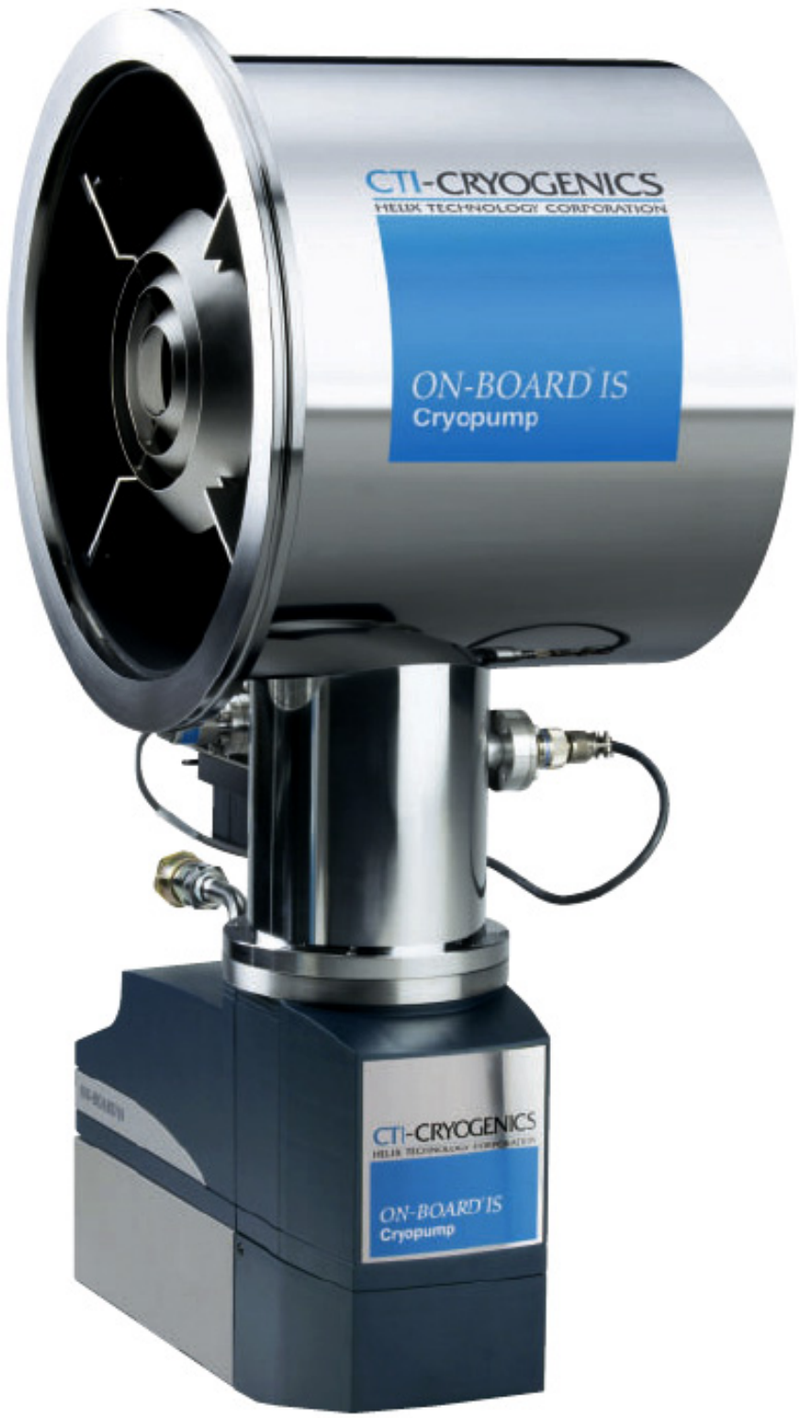
cannot handle continuous gas flow

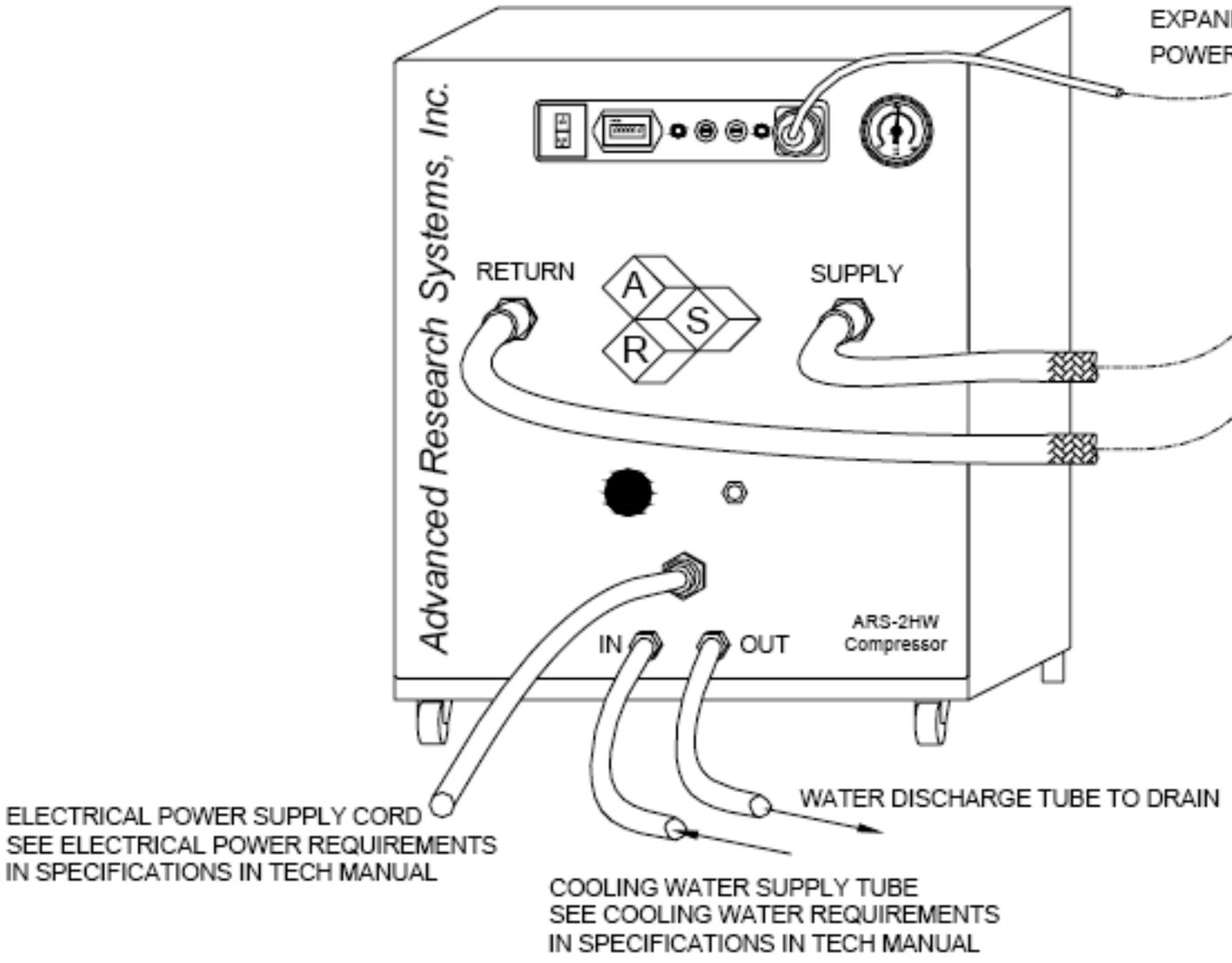
e. g. Ar capacity ~6000 liters

H_2 capacity ~ 46 liters

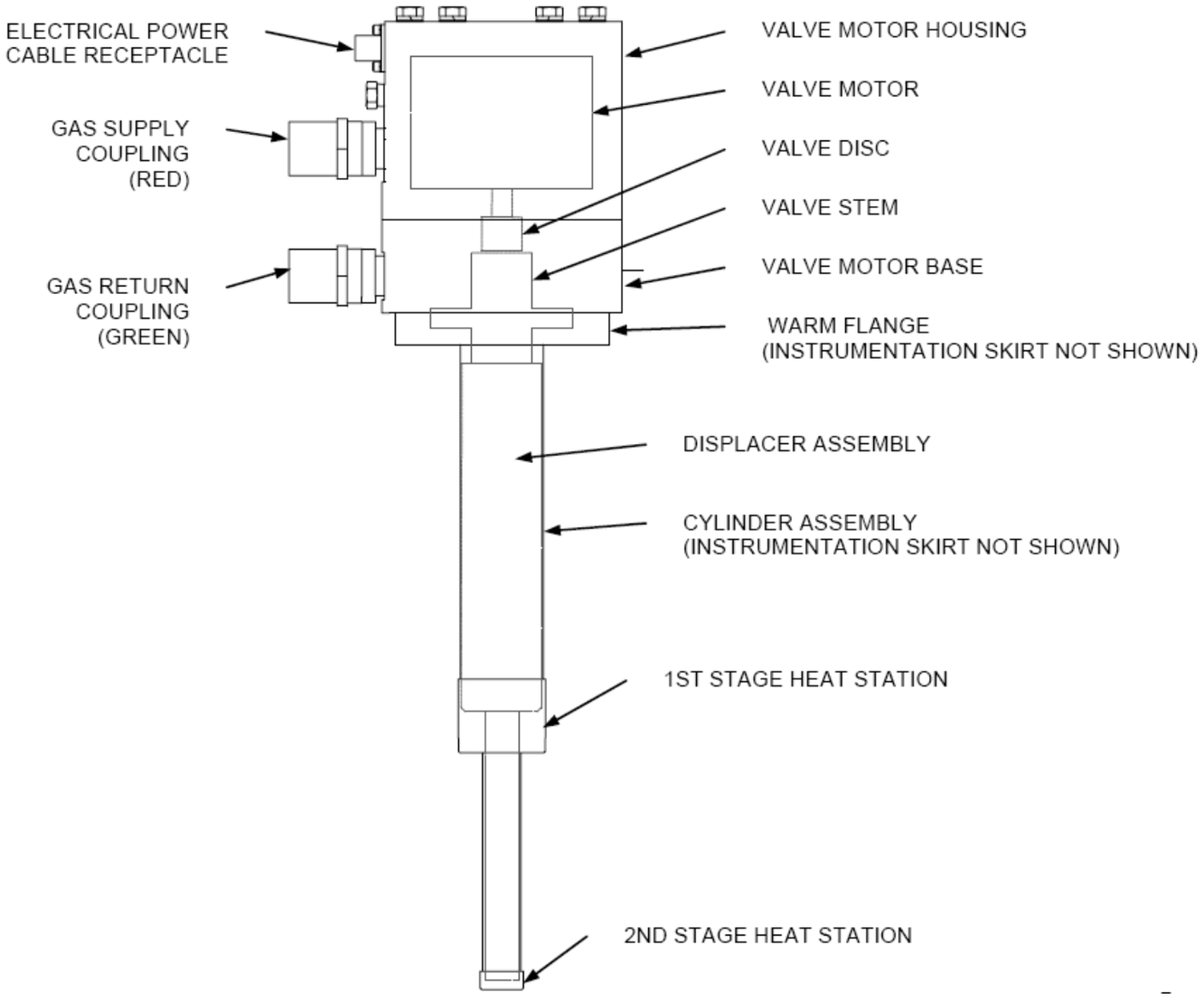
need to be regenerated frequently


Process Chamber
Cooled
Radiation Shield
Water Vapor
Frozen to a Vapor Pressure
of less than 10^{-15} Torr
65 K to 75 K
Surfaces
Ar, O_2, N_2
Frozen
Cold Head
10 K to 20 K
H_2, He, Ne
Adsorbed on Charcoal
(1000 m^2/g)
Expander
Compressor
and
Surge Volumes

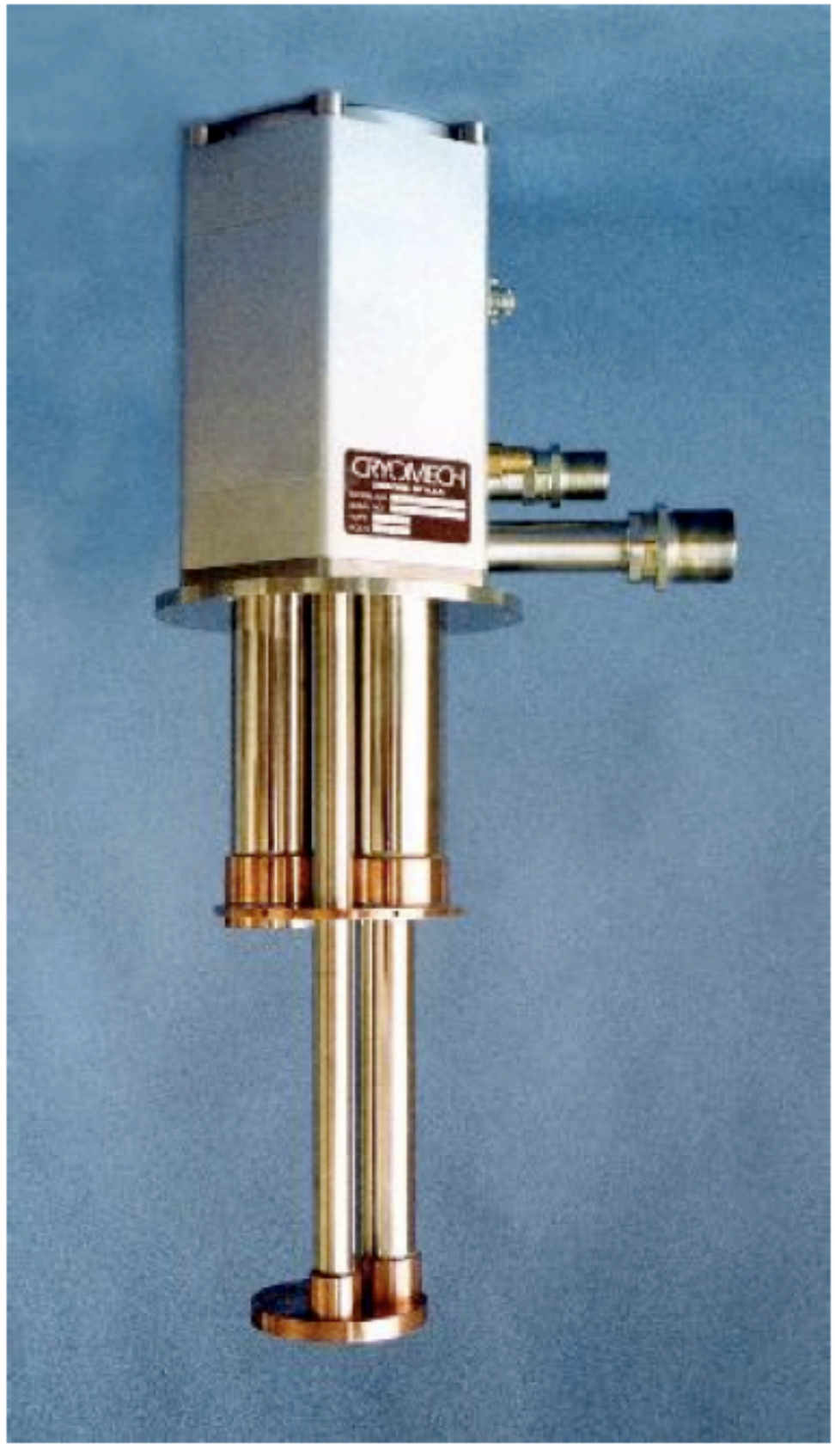

CTI-CRYOGENICS
HELIX TECHNOLOGY CORPORATION
ON-BOARD IS
Cryopump
CTI-CRYOGENICS
ON-BOARD IS
Cryopump


EXPANDER ELECTRICAL
POWER CABLE
EXPANDER
SUPPLY (RED)
GAS LINES
RETURN (GREEN)
RETURN
SUPPLY
A
S
R
Advanced Research Systems, Inc.
IN
OUT
ARS-2HW
Compressor
WATER DISCHARGE TUBE TO DRAIN
ELECTRICAL POWER SUPPLY CORD
SEE ELECTRICAL POWER REQUIREMENTS
IN SPECIFICATIONS IN TECH MANUAL
COOLING WATER SUPPLY TUBE
SEE COOLING WATER REQUIREMENTS
IN SPECIFICATIONS IN TECH MANUAL

Cold head



Gifford-McMahon



PT - pulsating tube

Cryo-Plex® 16

Pumping Speed

Air	5000 l/s
Water	16000 l/s
Hydrogen	5000 l/s
Argon	4200 l/s

Throughput

Argon	500 scc/min.

Capacity

Argon	2500 std. liters
Hydrogen	15 std. liters

(at 5 x 10^{-6} torr)

Crossover

300 torr liters

Cooldown Time

2.5 hours

Inlet Flange

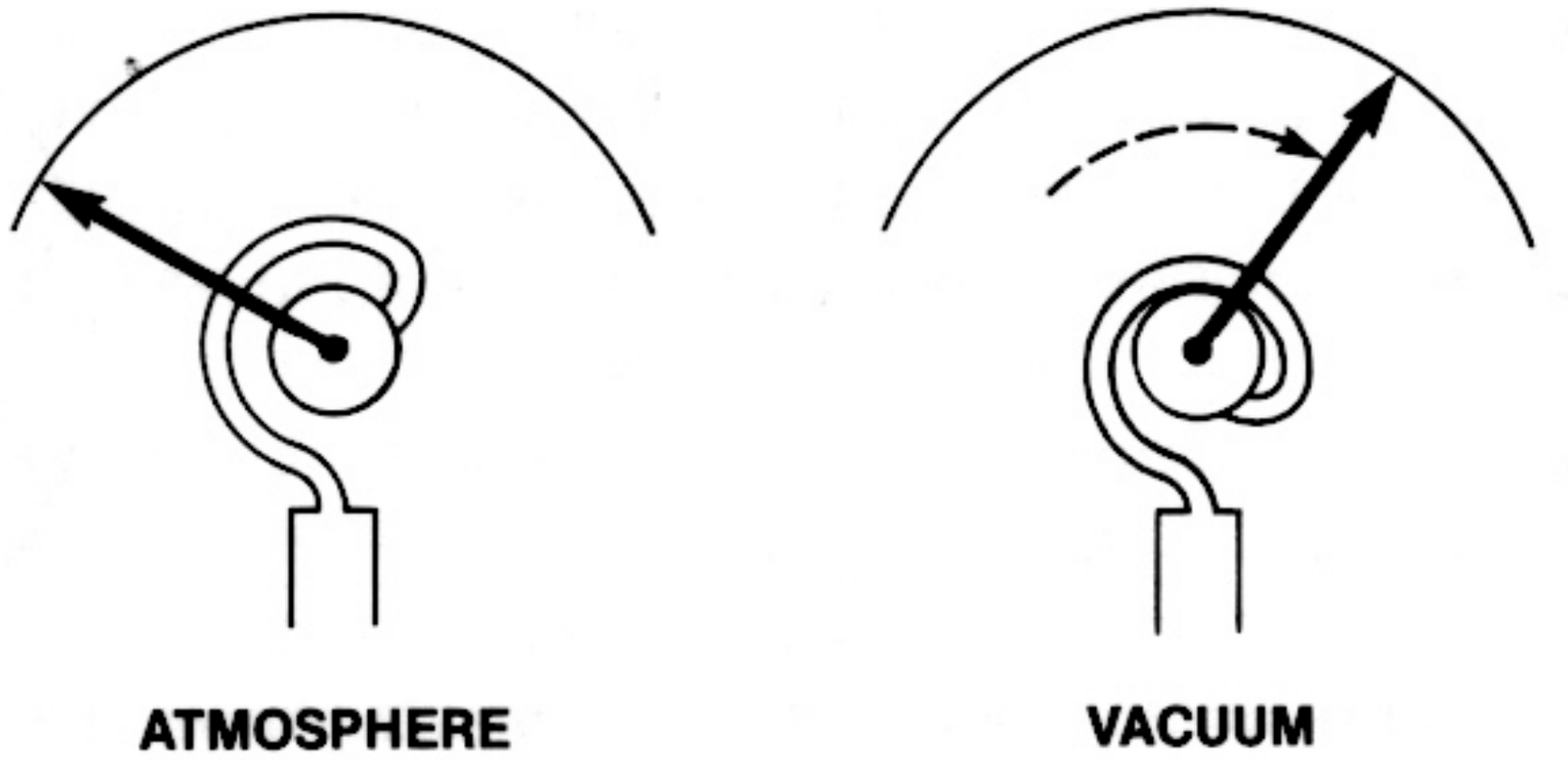
16 inch CVC
(17.7 inch O.D.)
ISO NW 400
10 inch CF

Dimensions

Height 24.0 inches
Weight 160 pounds

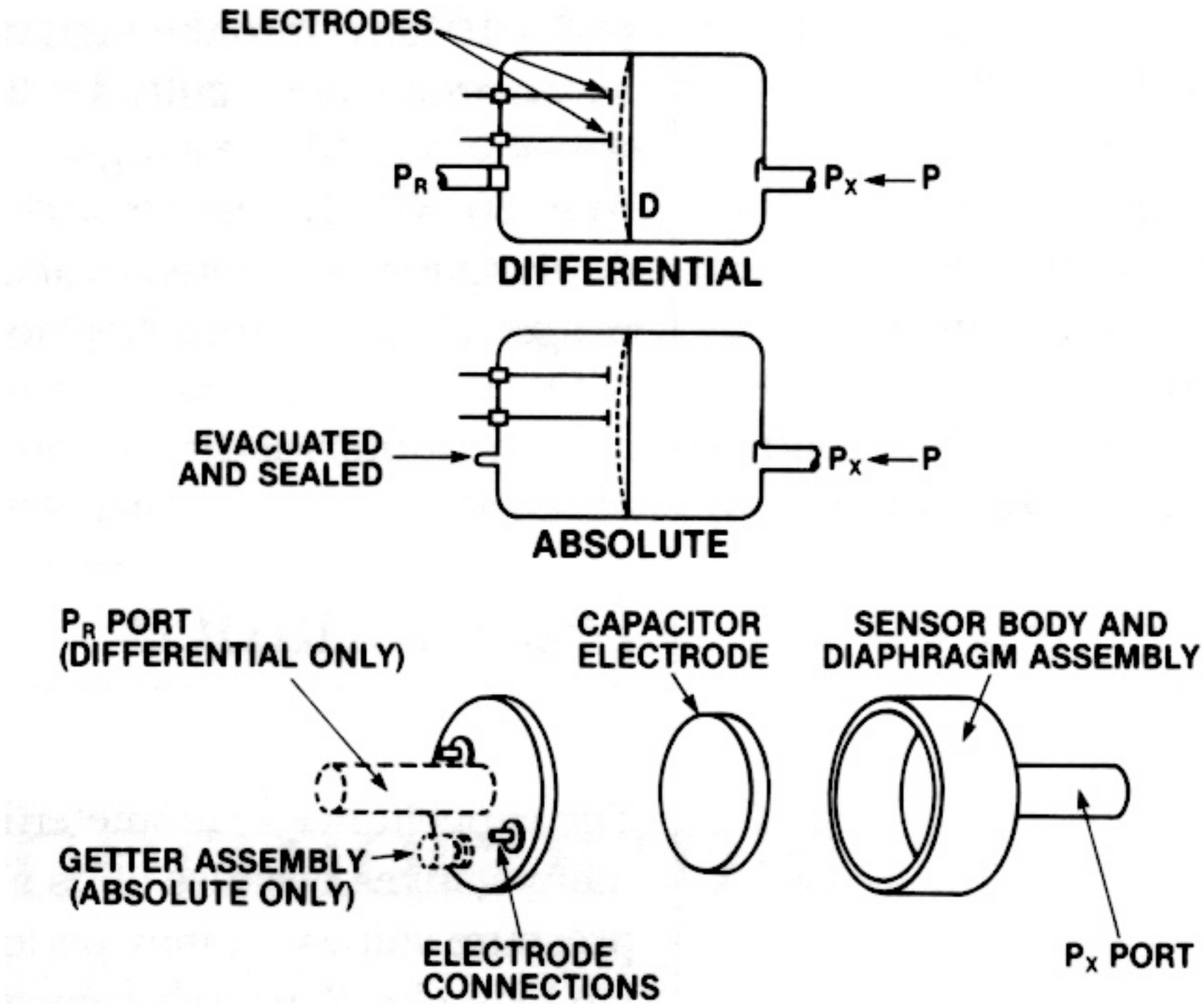
Vacuum gauges

Simple mechanical



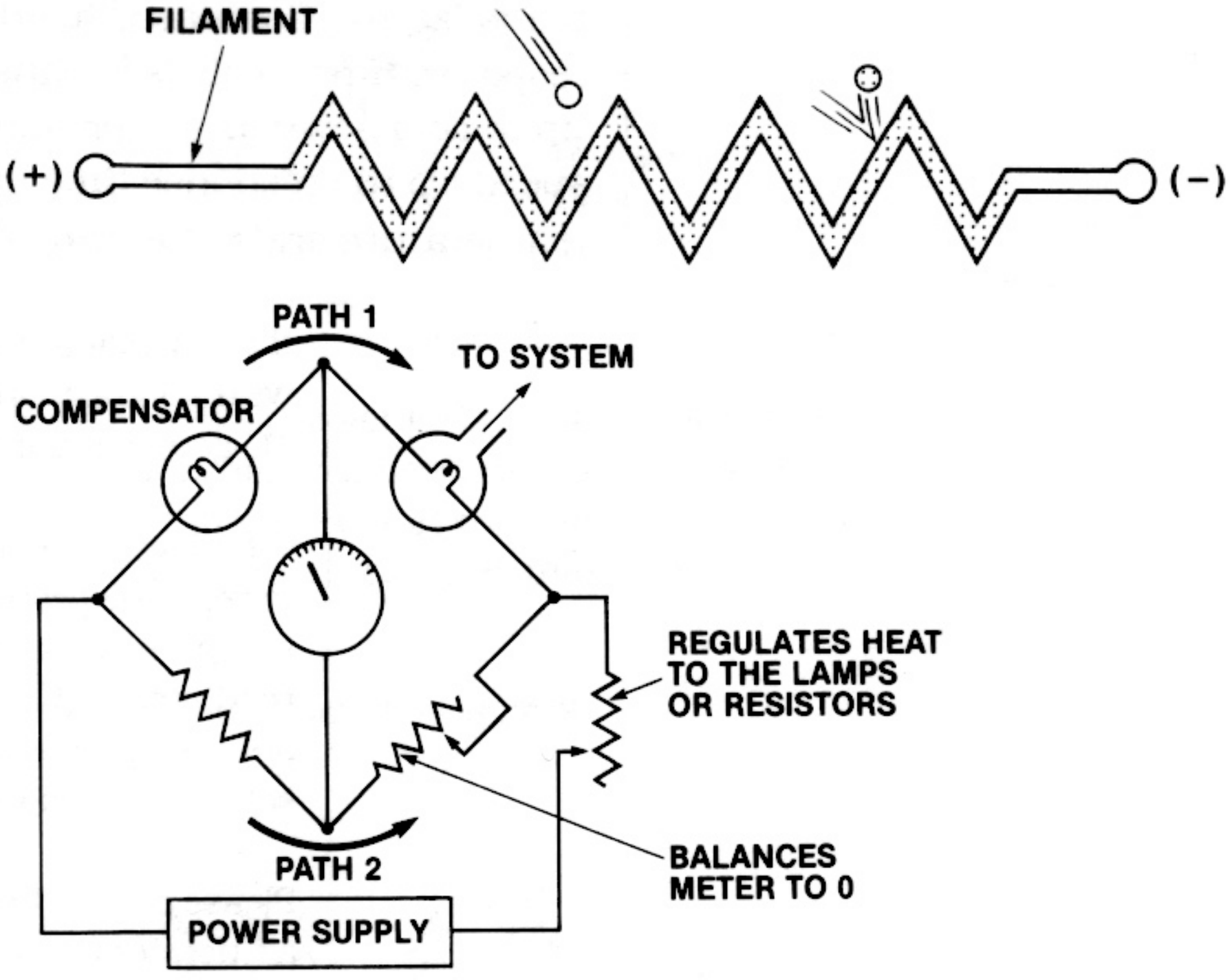
good down to ~10 Tr, simple, inexpensive

Mechanical - capacitance gauge



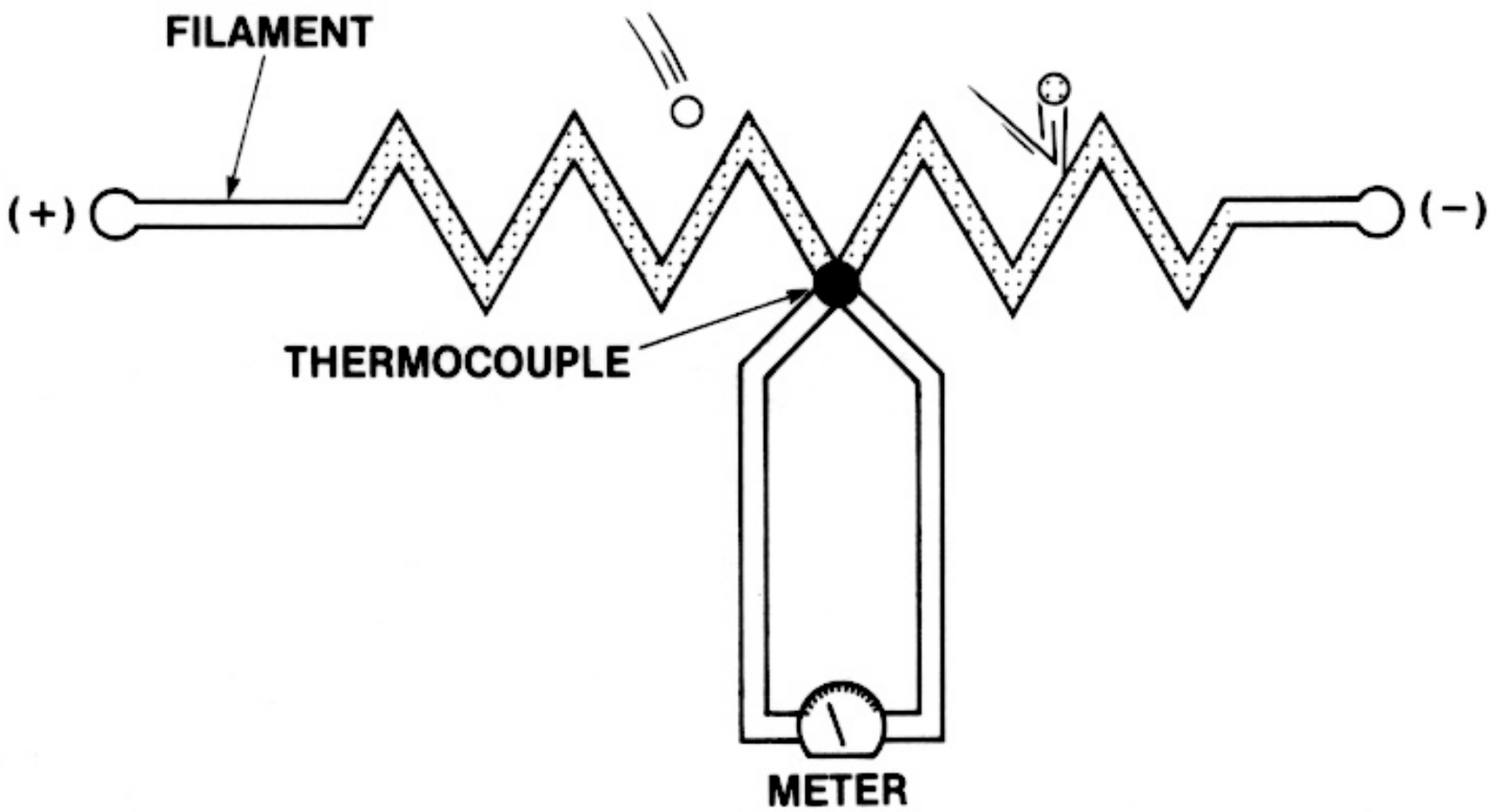
good down to ~10^{-2} Tr

Heat transfer - Pirani gauge

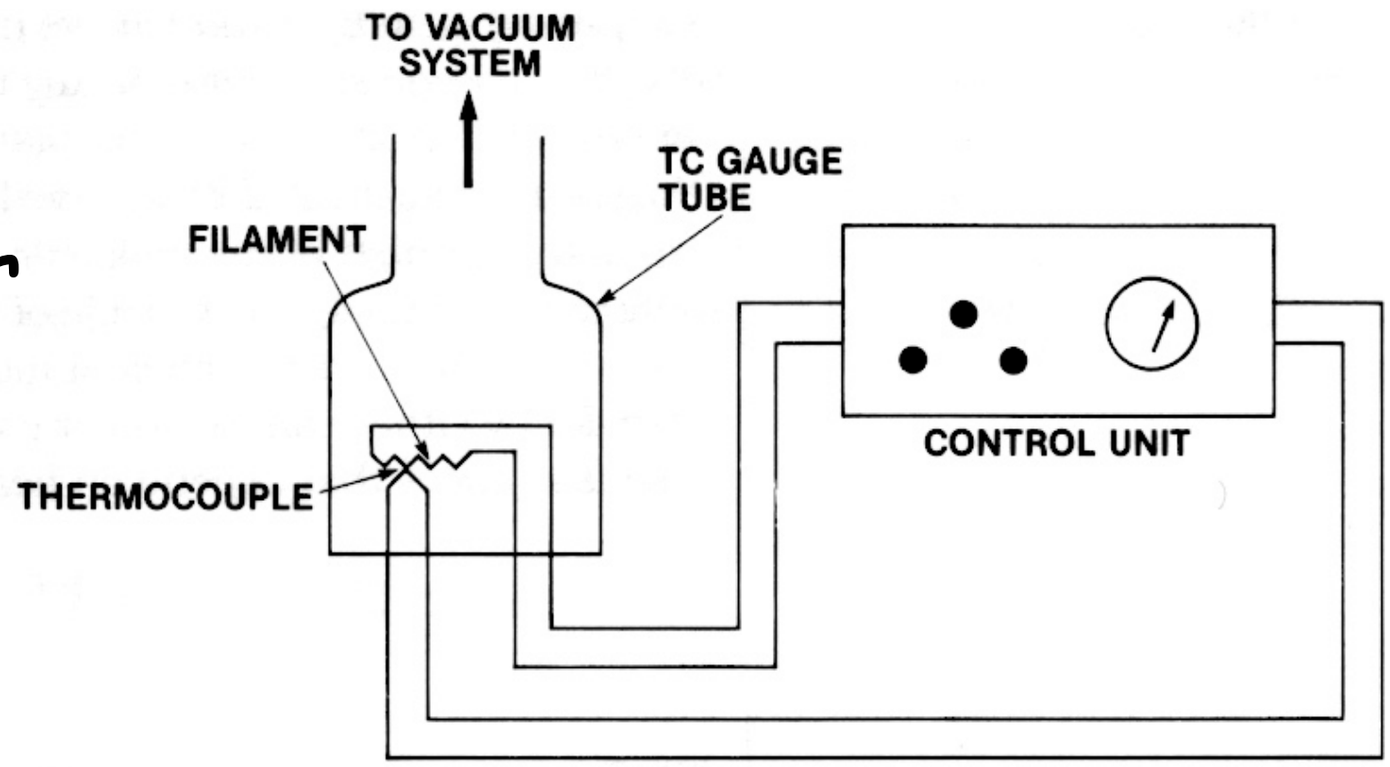


good down to ~10^{-3} Tr

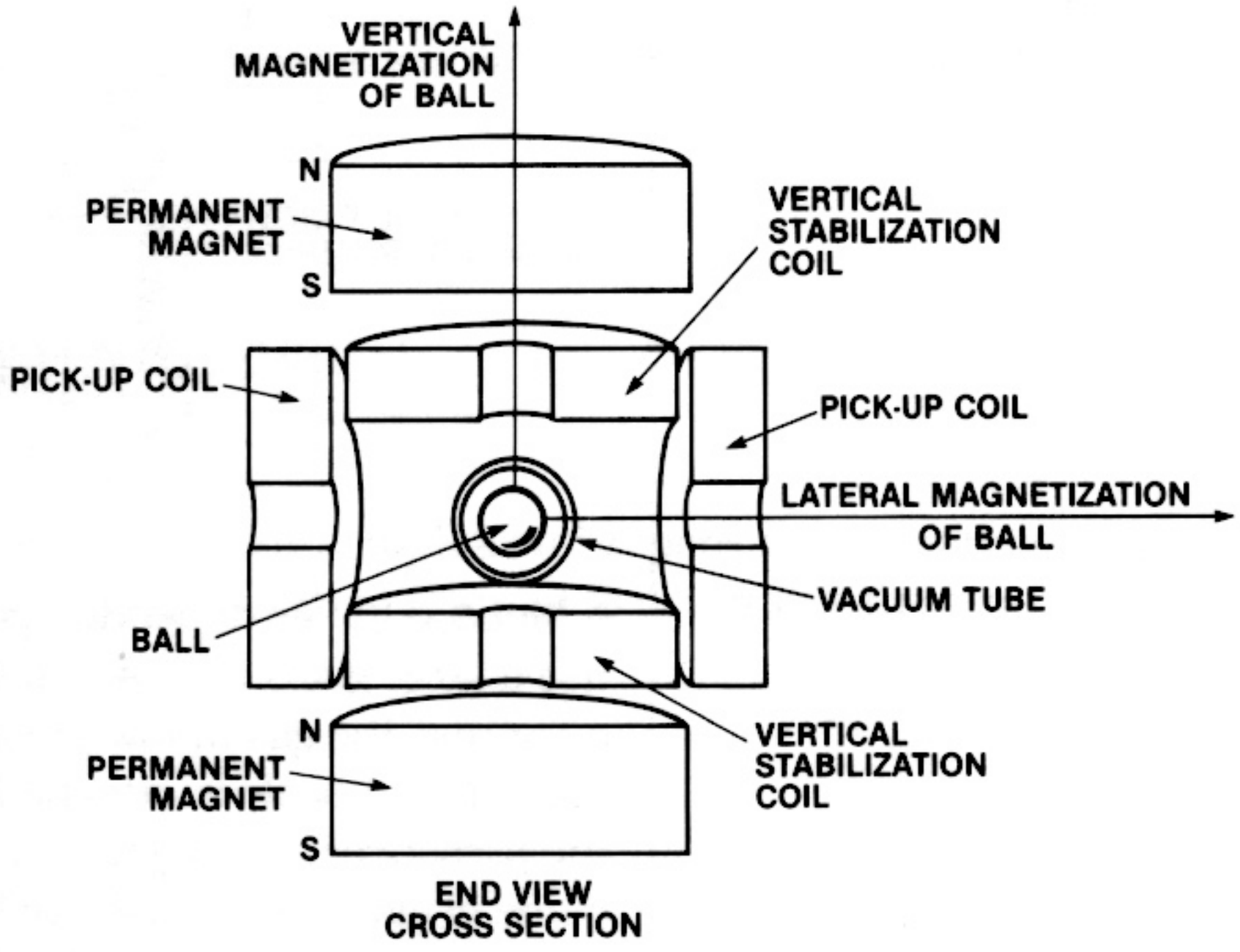
Heat transfer - thermocouple gauge



good down to ~10^{-4} Tr

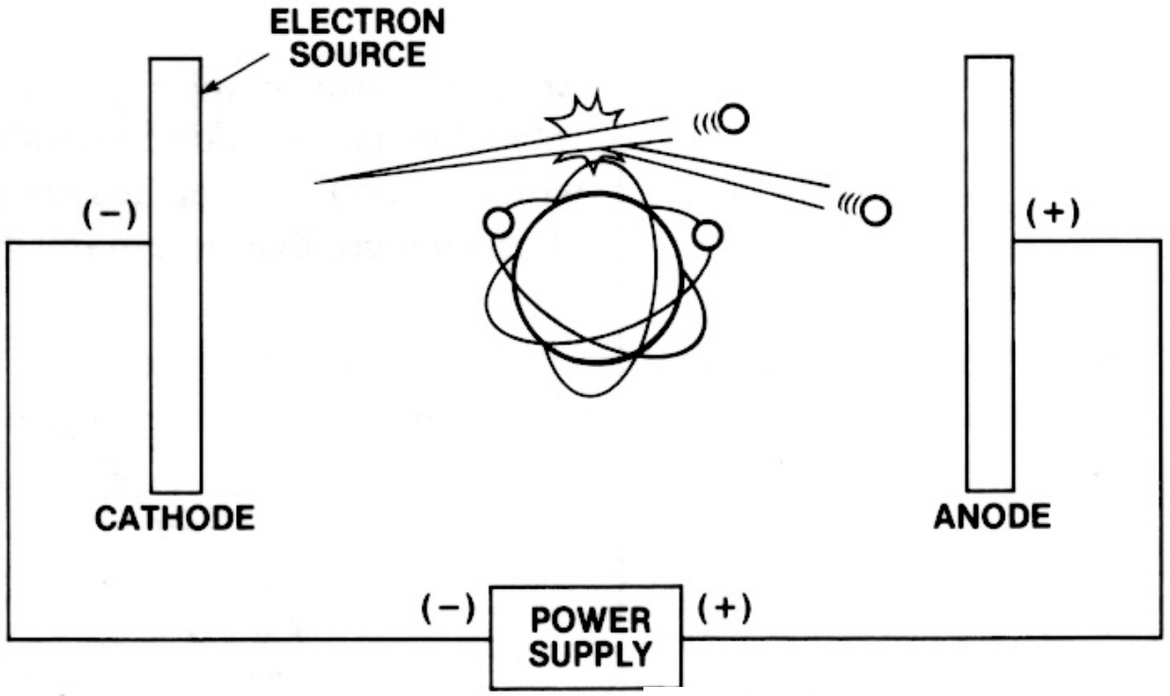


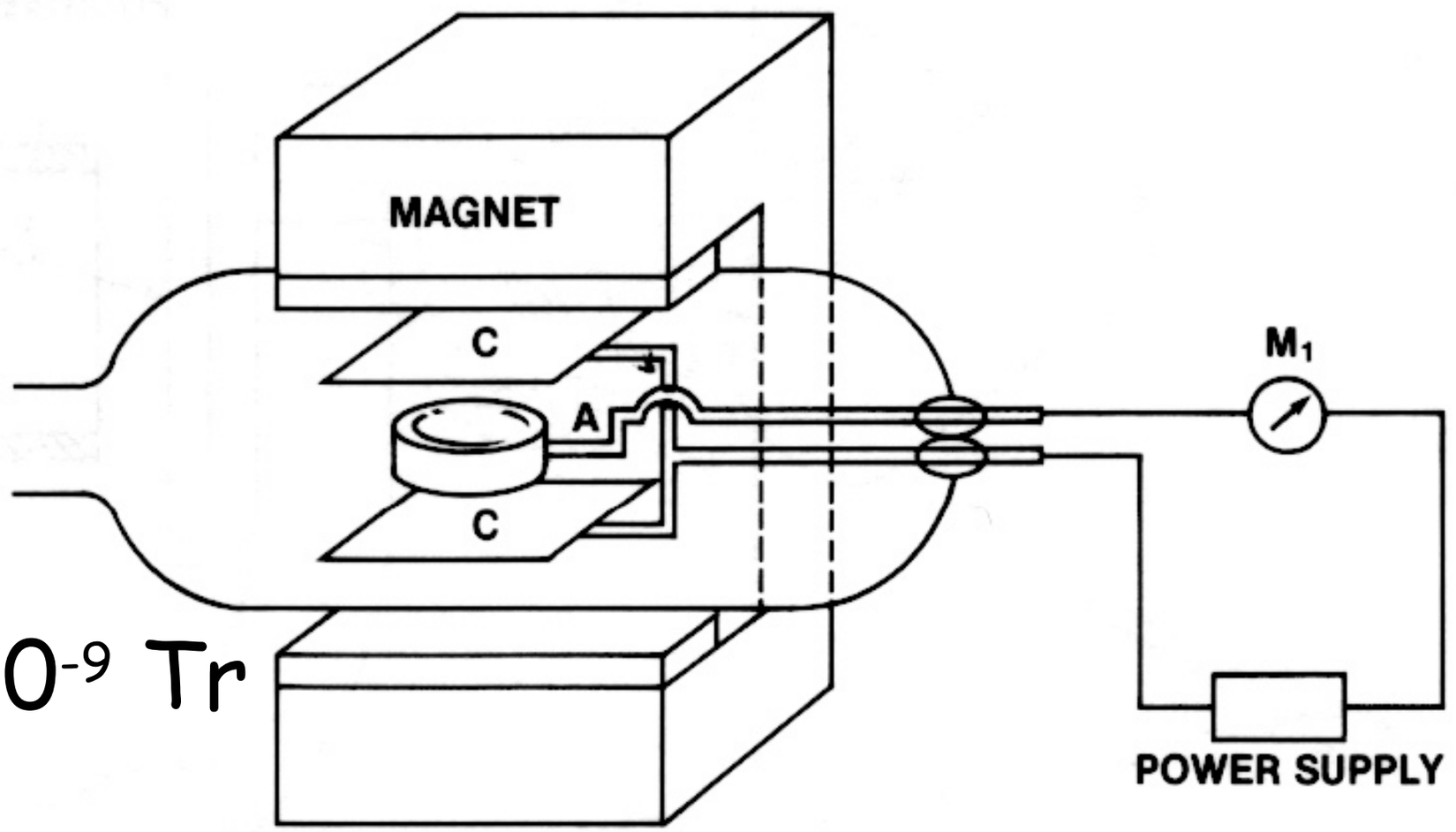
Primary calibration - rotating ball gauge



SPINNING ROTOR GAUGE

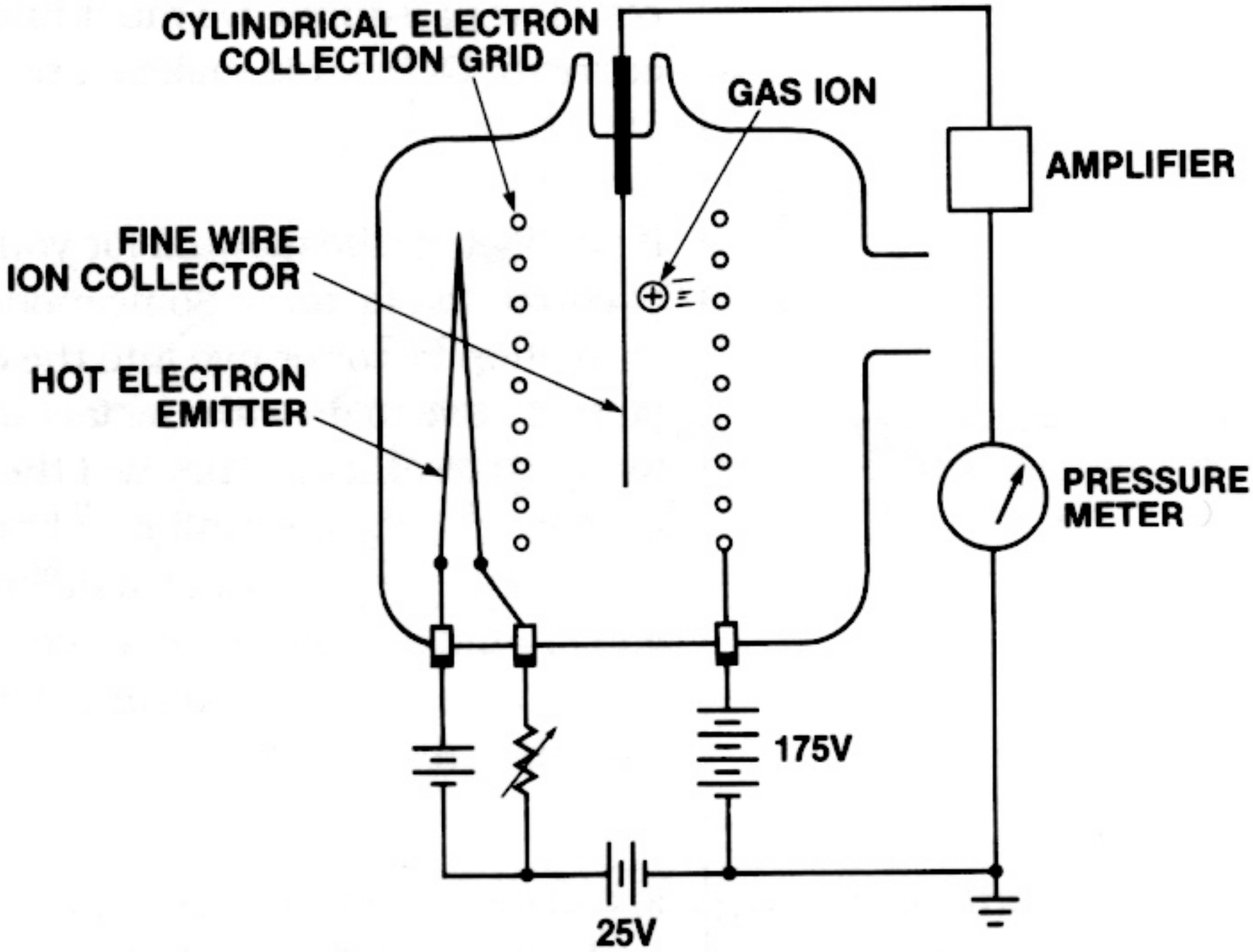
Cold cathode gauge





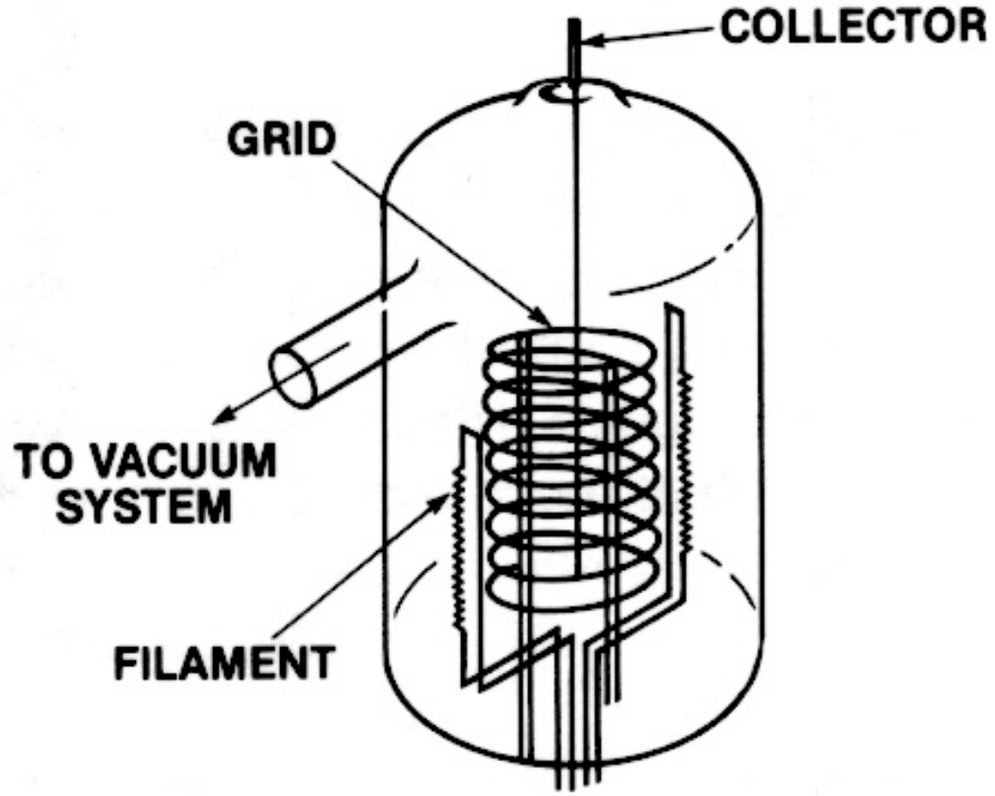
good down to ~10^{-9} Tr

Ion gauge

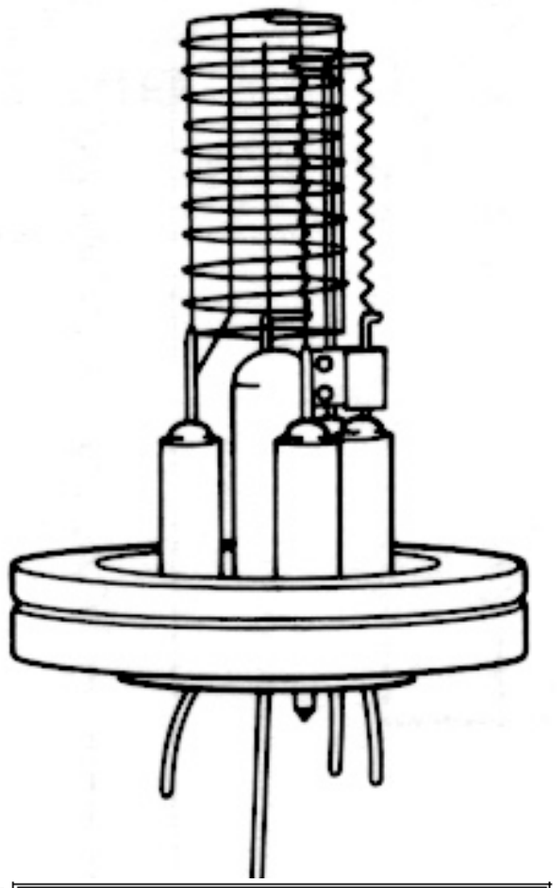


good down to ~10^{-12} Tr

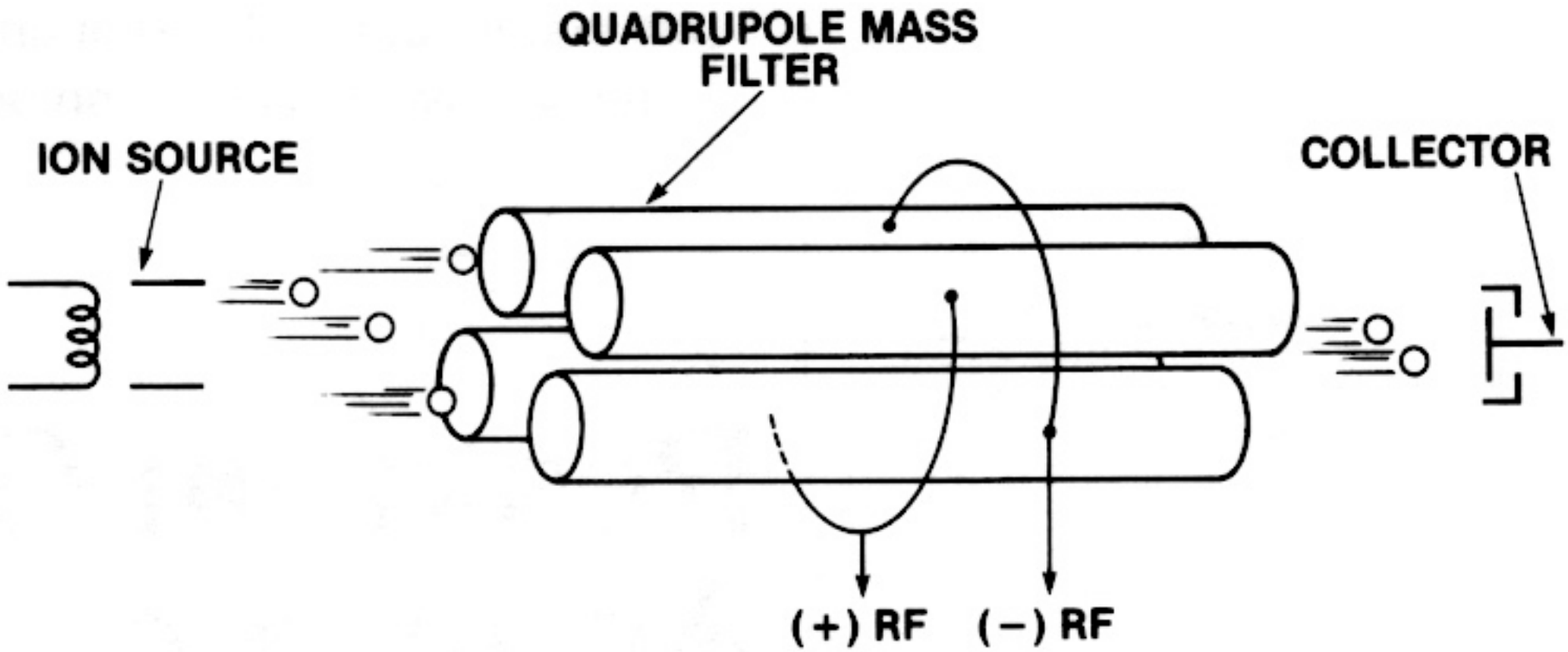
Byard Alpert glass gauge

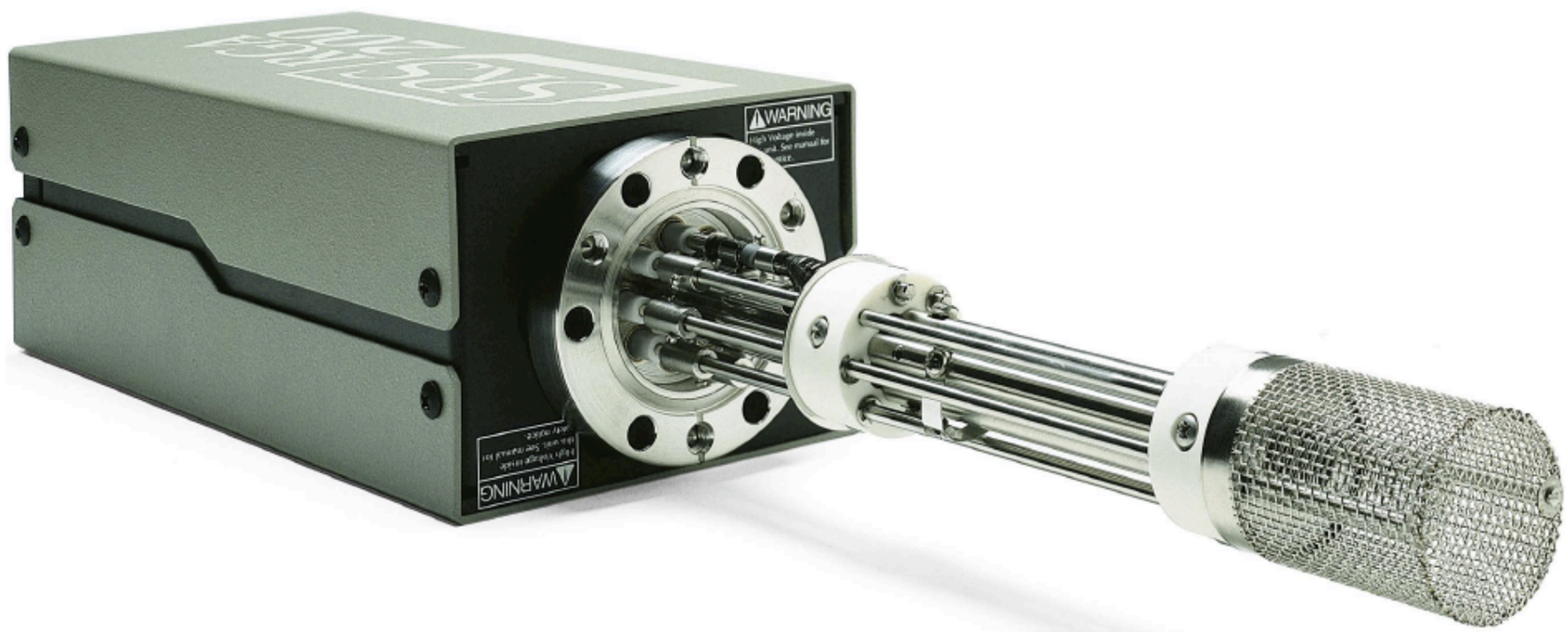


"Nude" gauge

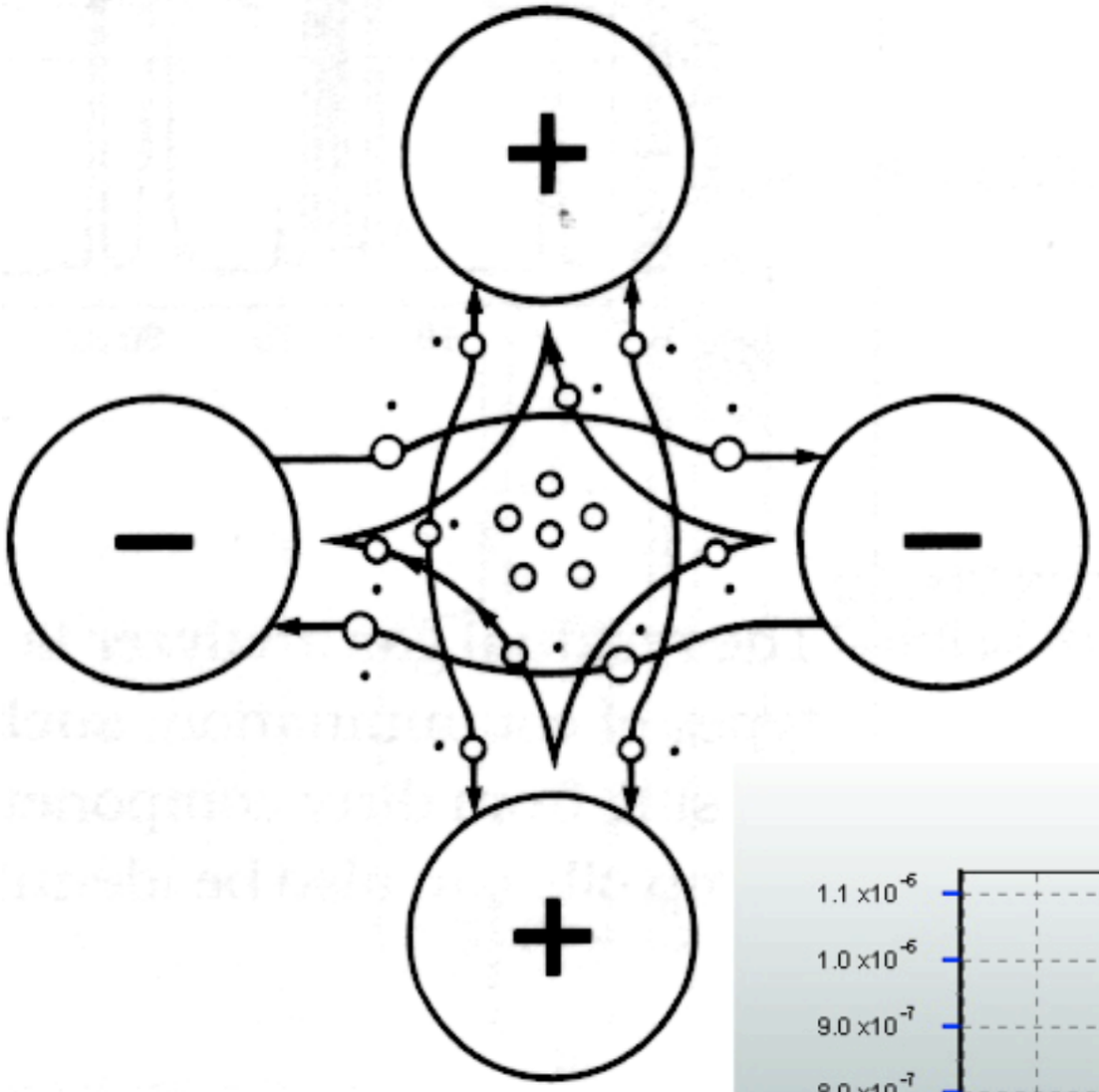


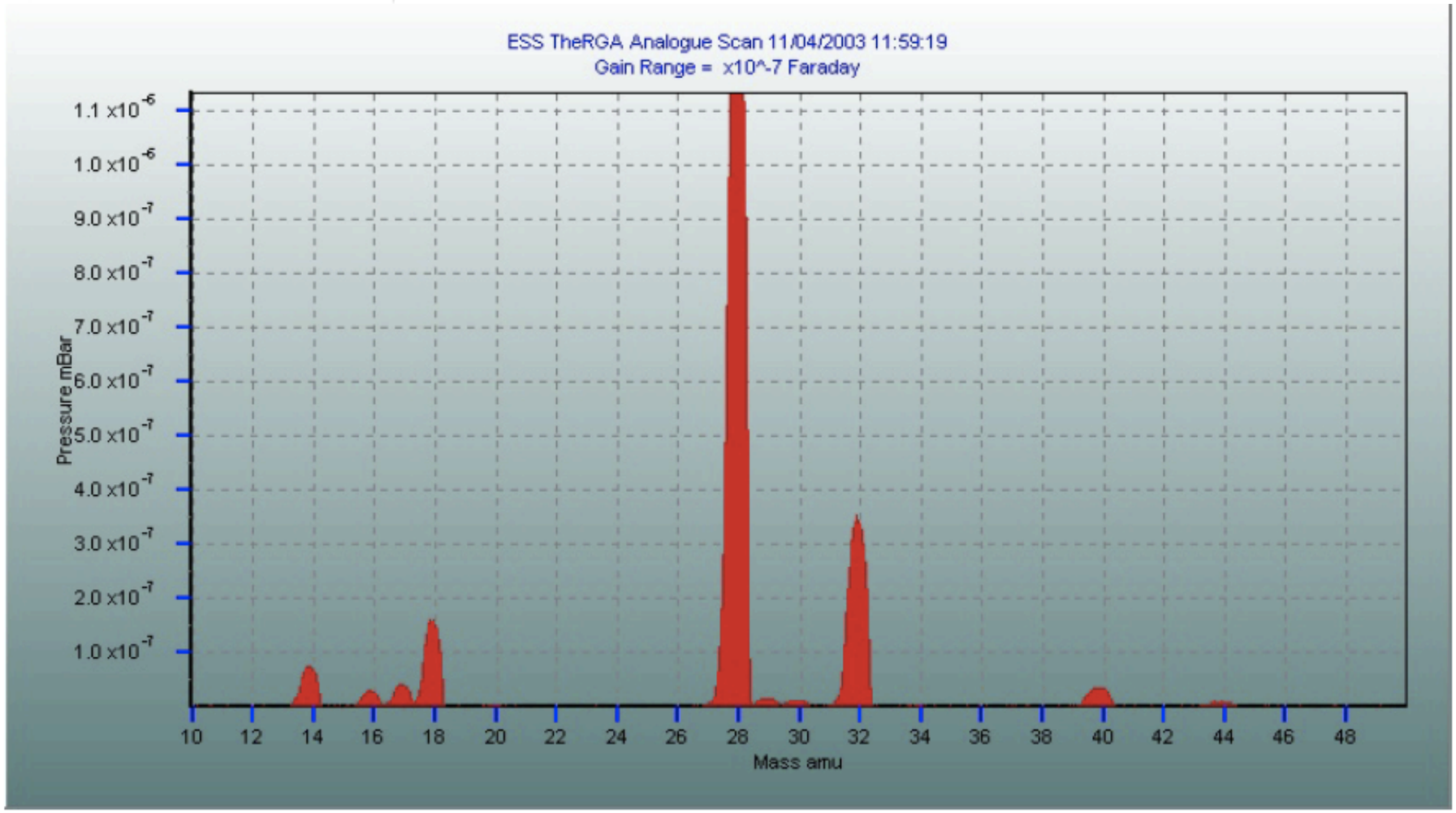
Residual gas analyzer (RGA)



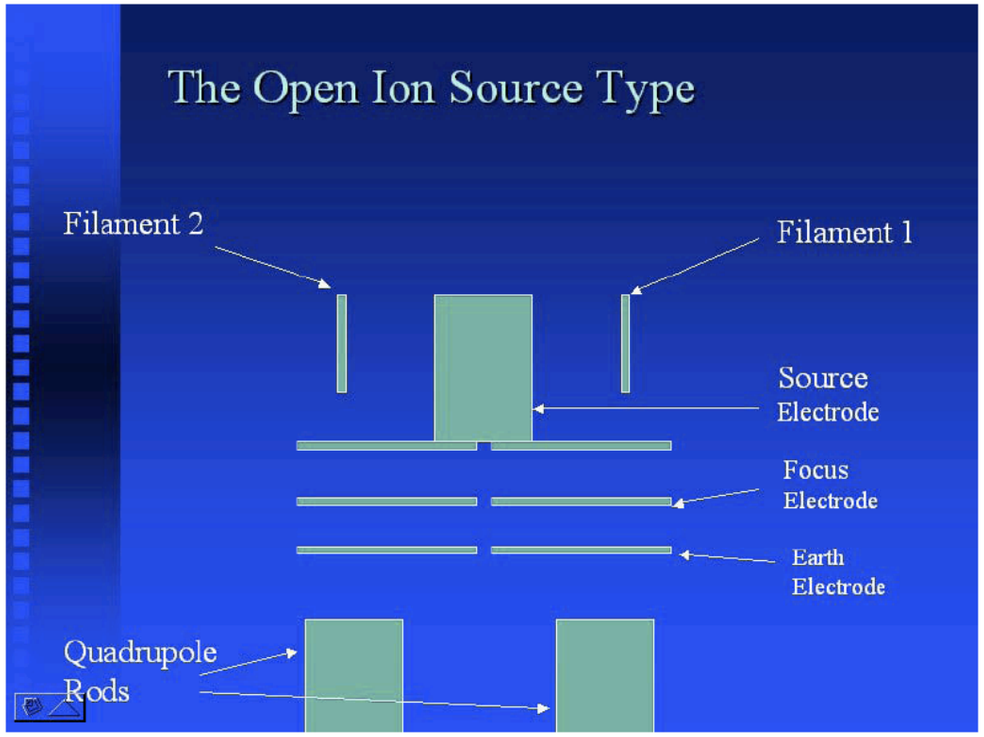


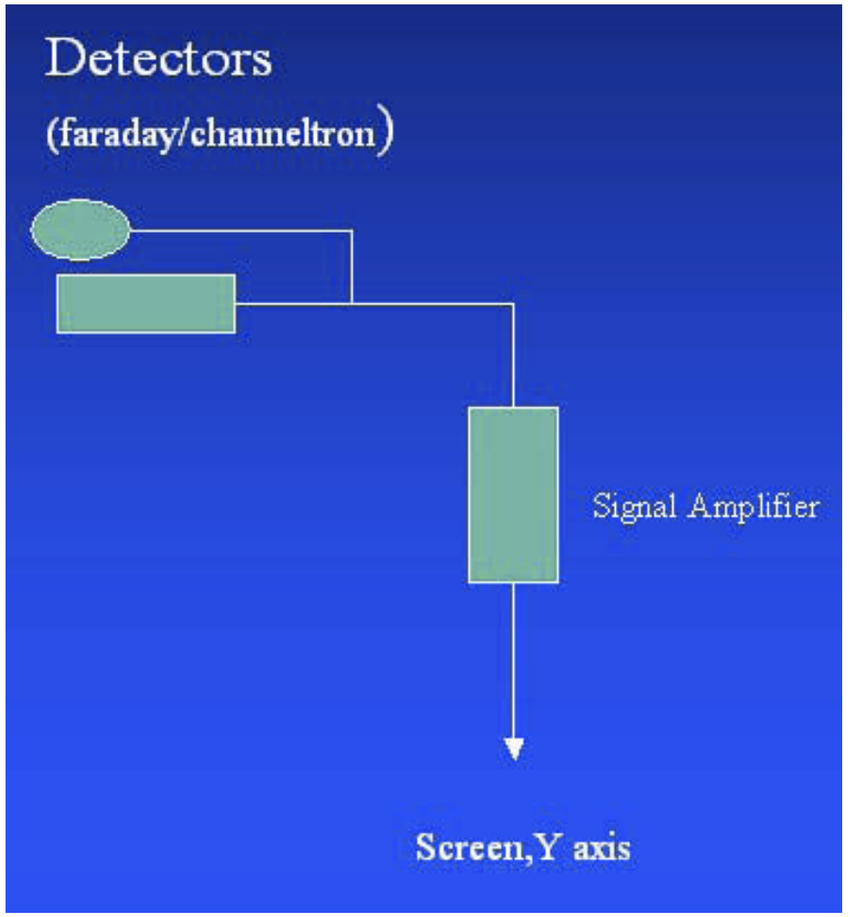
QUADRUPOLE MASS FILTER

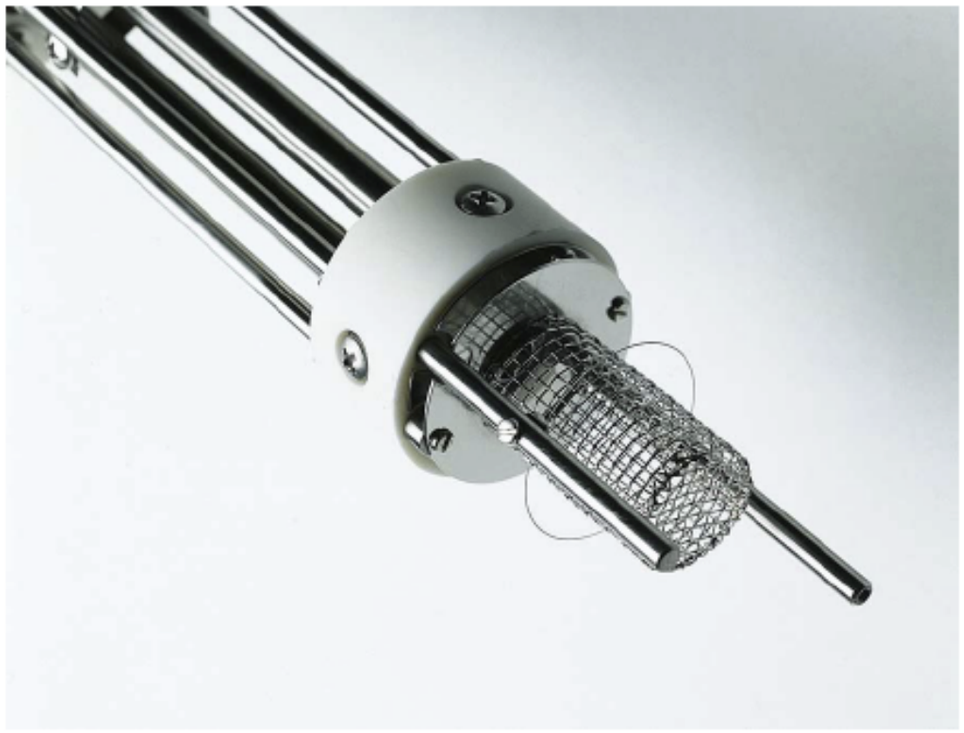


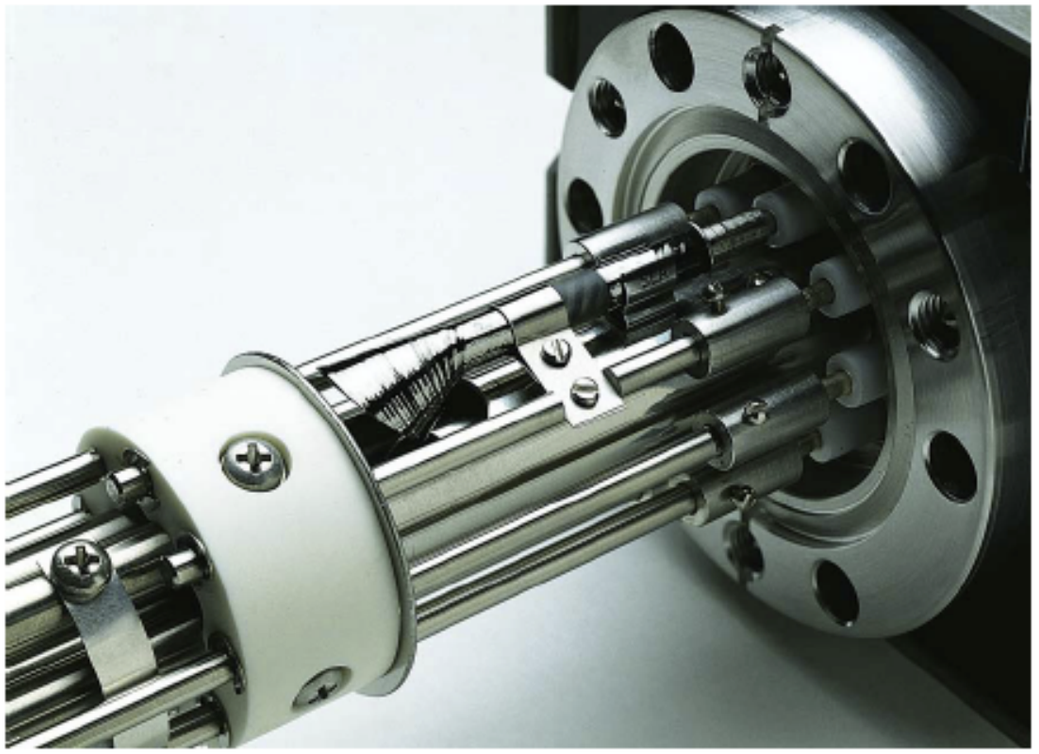


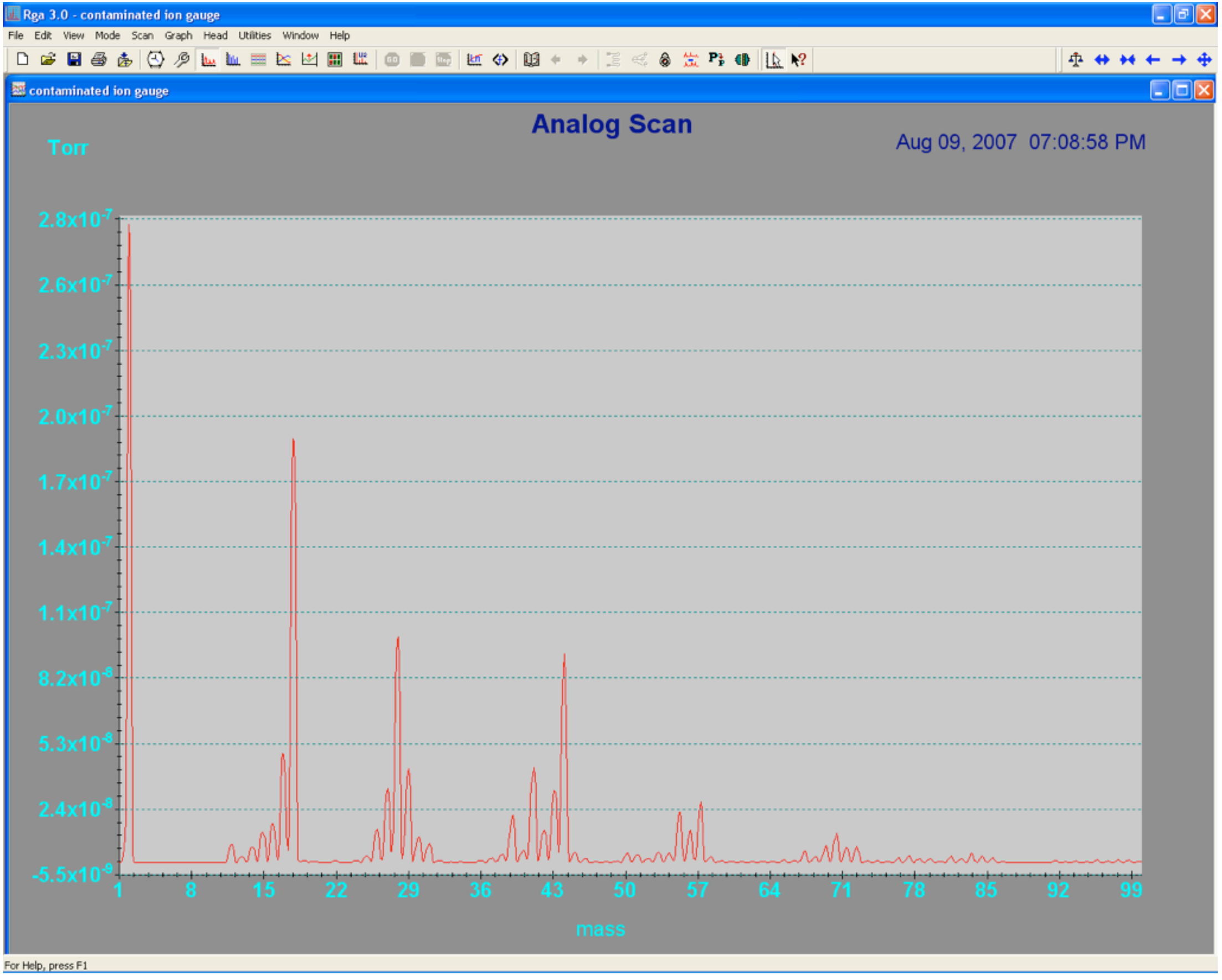
Ion source and detector










Rga 3.0 - contaminated ion gauge
File Edit View Mode Scan Graph Head Utilities Window Help
contaminated ion gauge
Analog Scan
Torr
Aug 09, 2007 07:08:58 PM
2.8x10-7
2.6x10-7
2.3x10-7
2.0x10-7
1.7x10-7
1.4x10-7
1.1x10-7
8.2x10-8
5.3x10-8
2.4x10-8
-5.5x10-9
1 8 15 22 29 36 43 50 57 64 71 78 85 92 99
mass
For Help, press F1

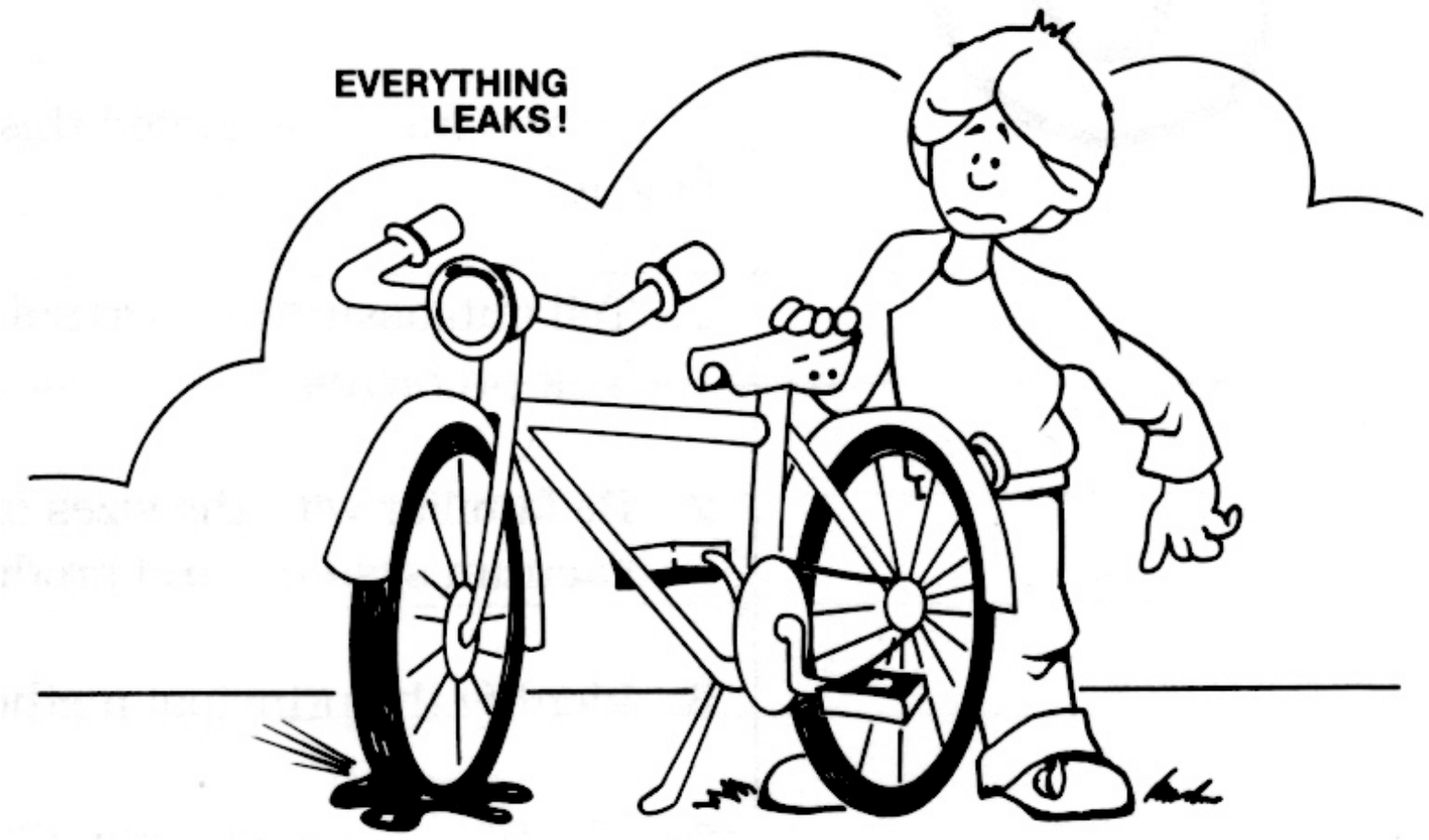
Vacuum practice, tips etc.

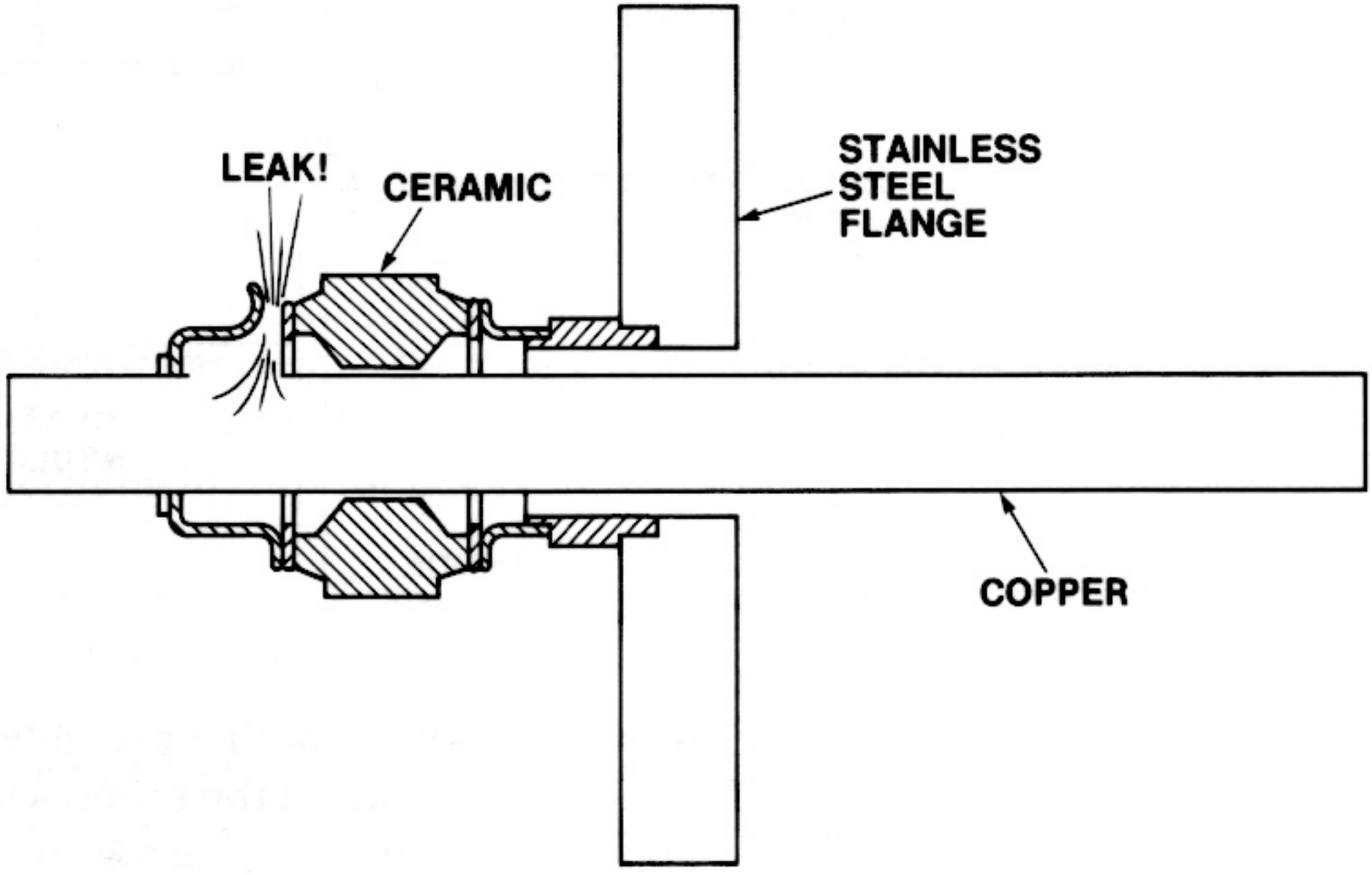
real leaks

caused by cracks, bad seals, bad welds, material fatigue etc.

large and small are easy to detect

medium and very small may cause difficulties

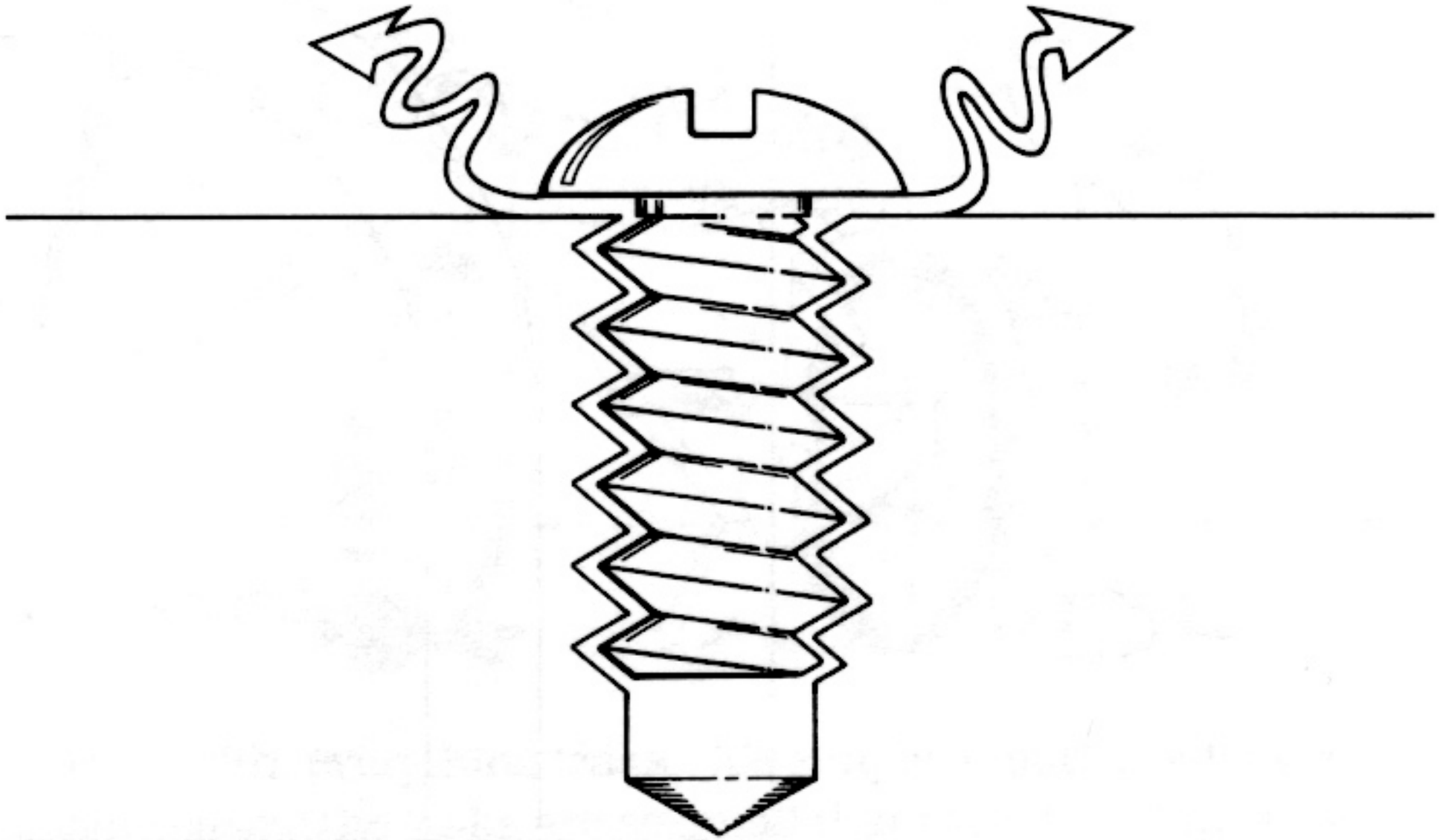




virtual leaks

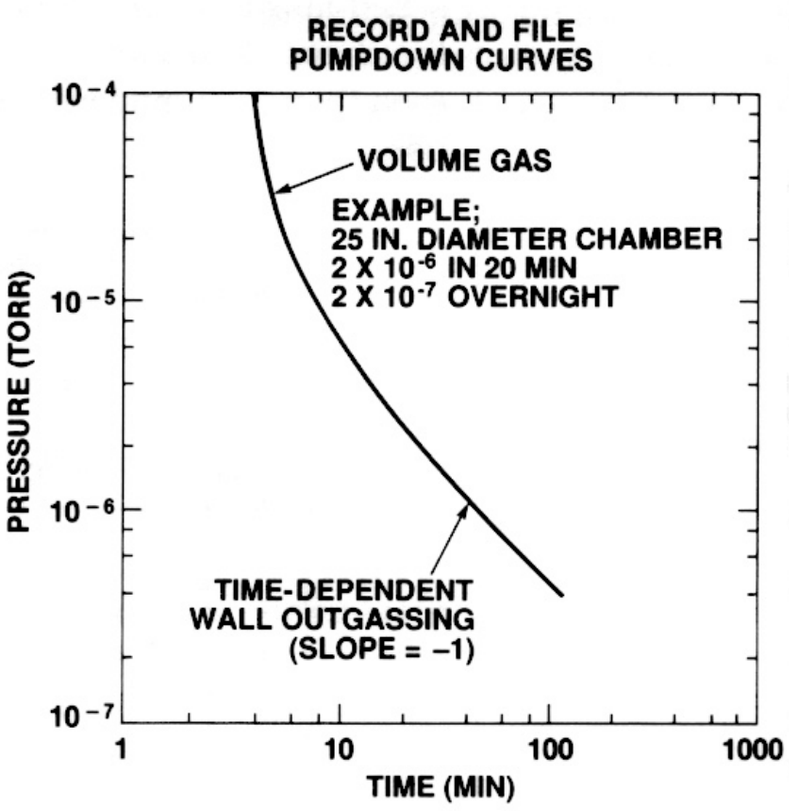
very difficult to detect

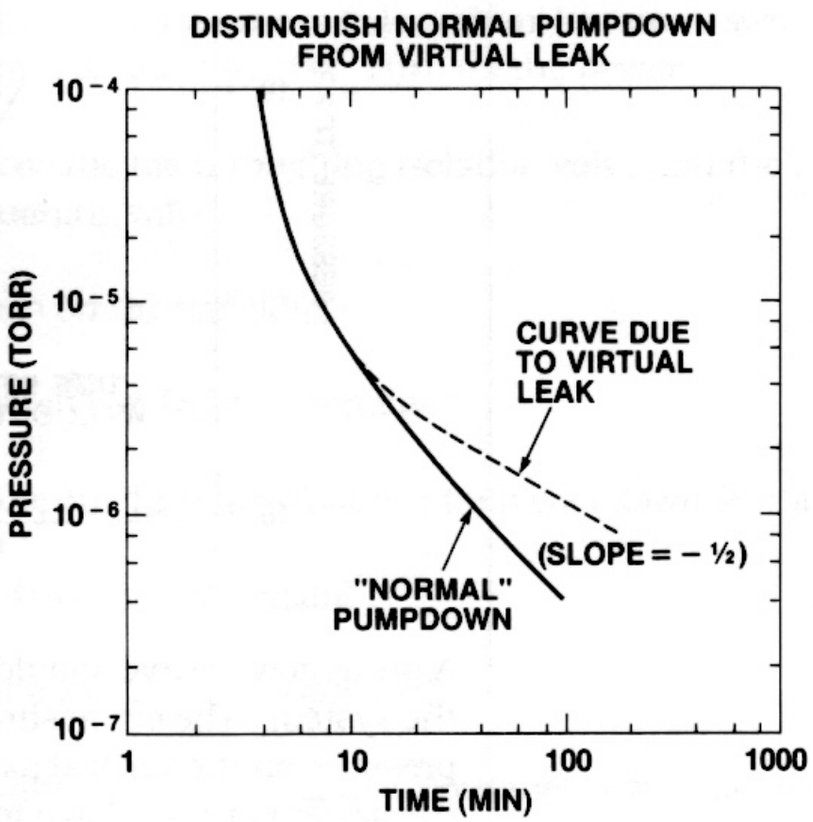
use good practice in design and construction

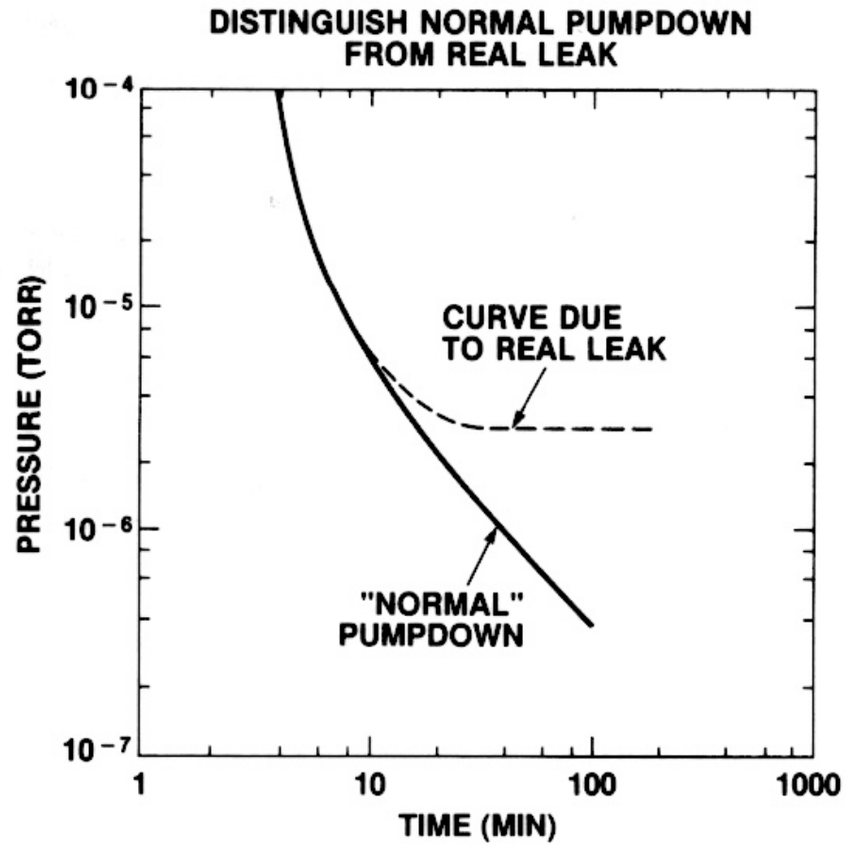


leak detection

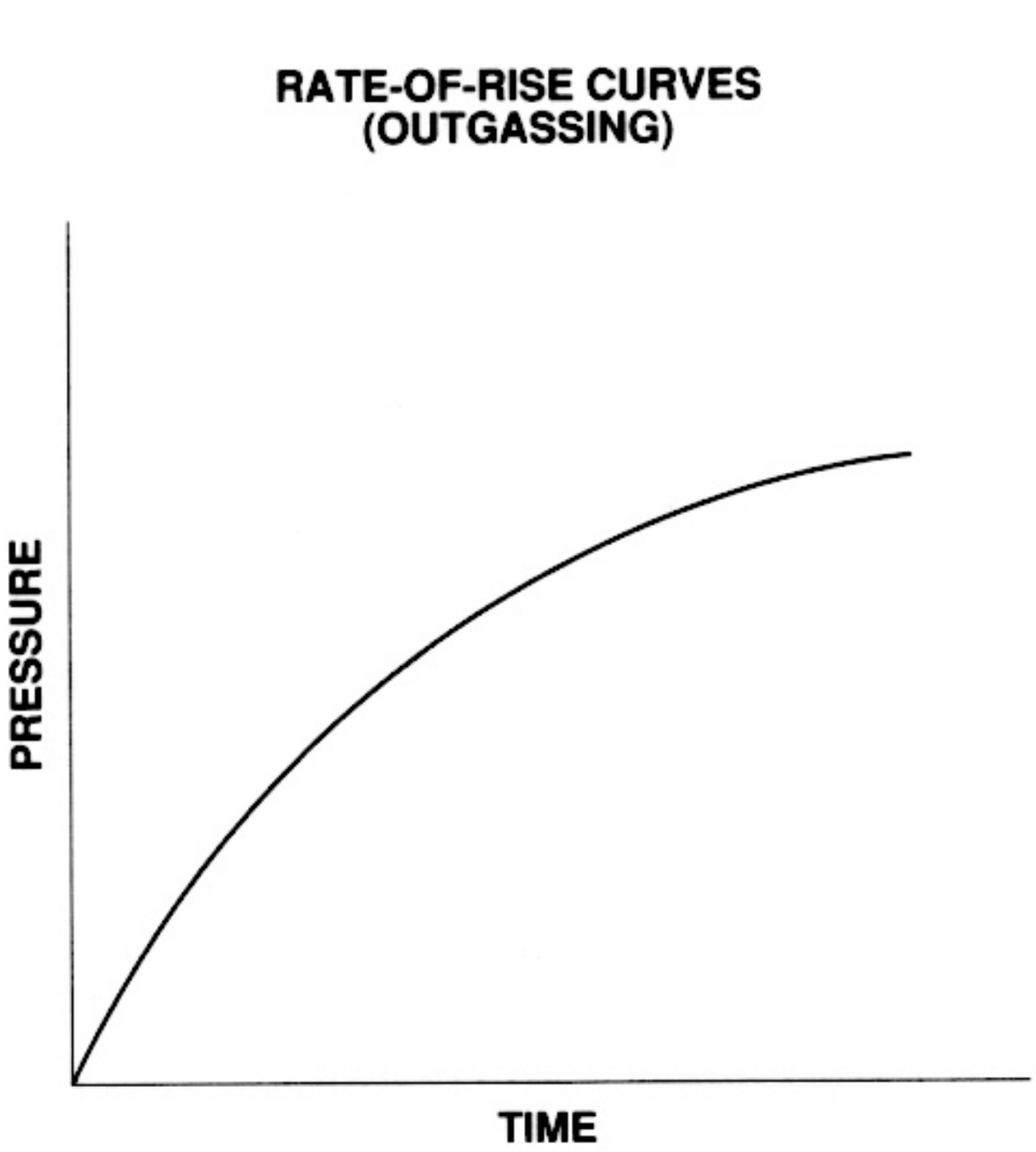
first question: is there a leak - know your vacuum system

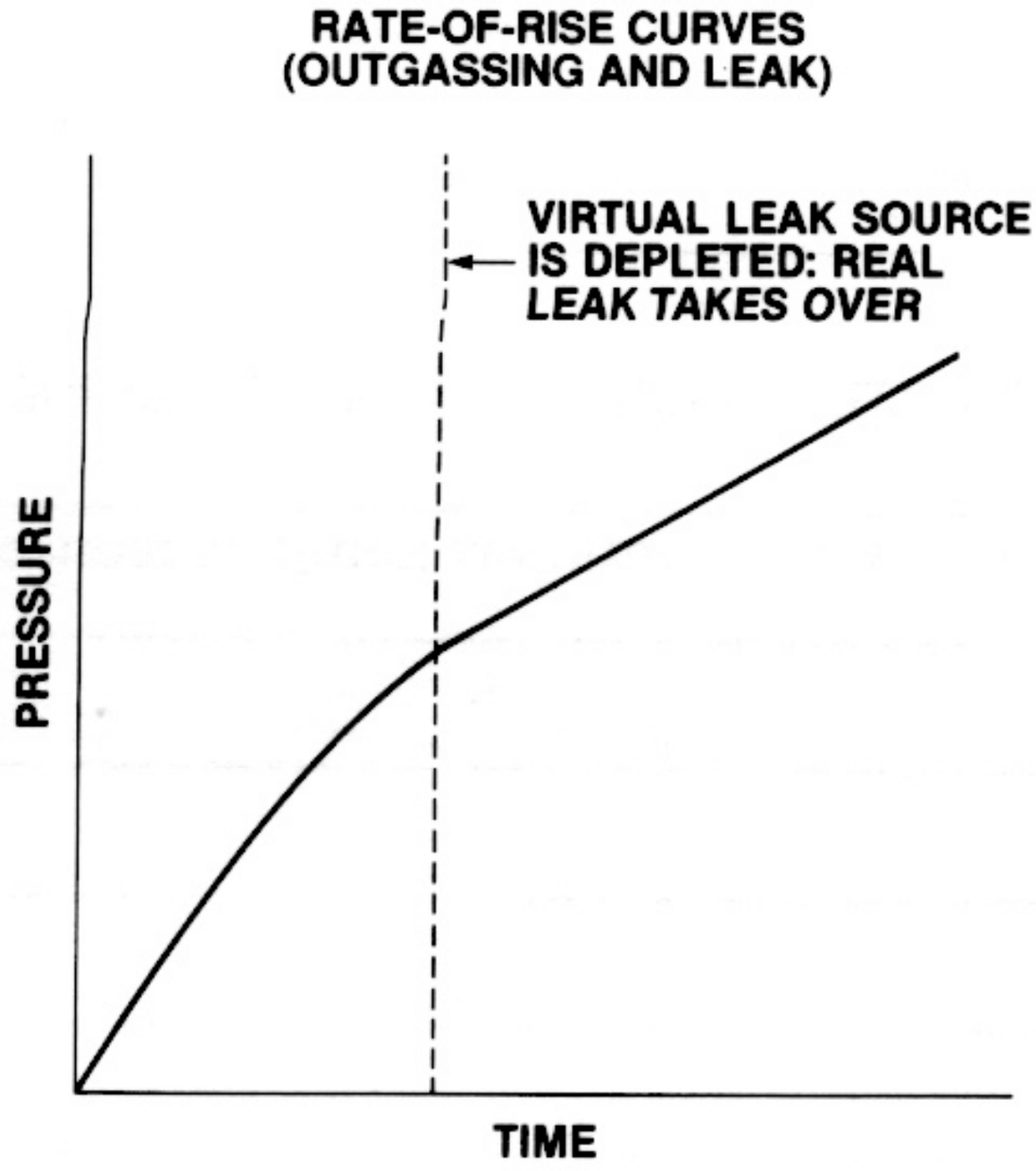




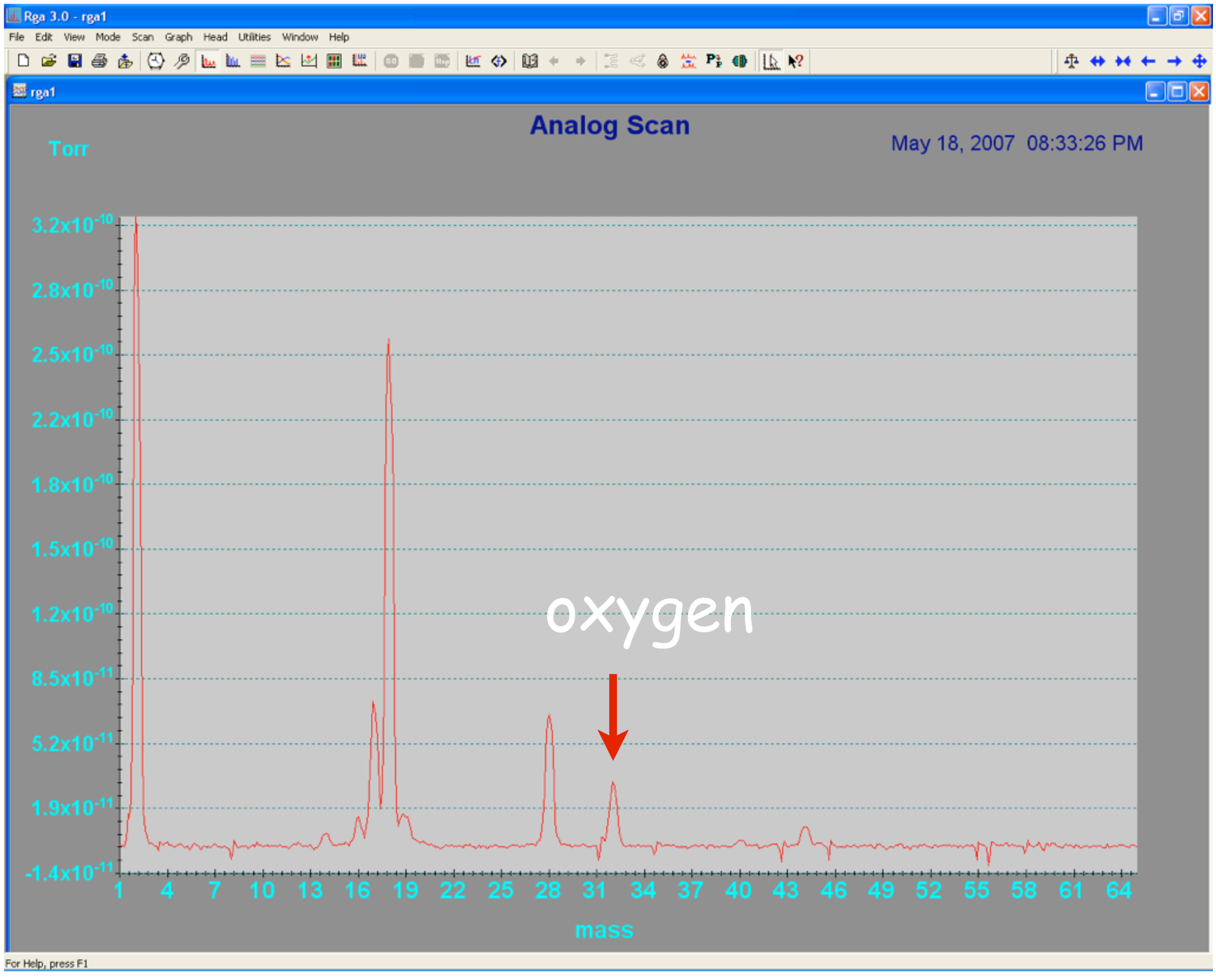


close pump and observe how pressure increases

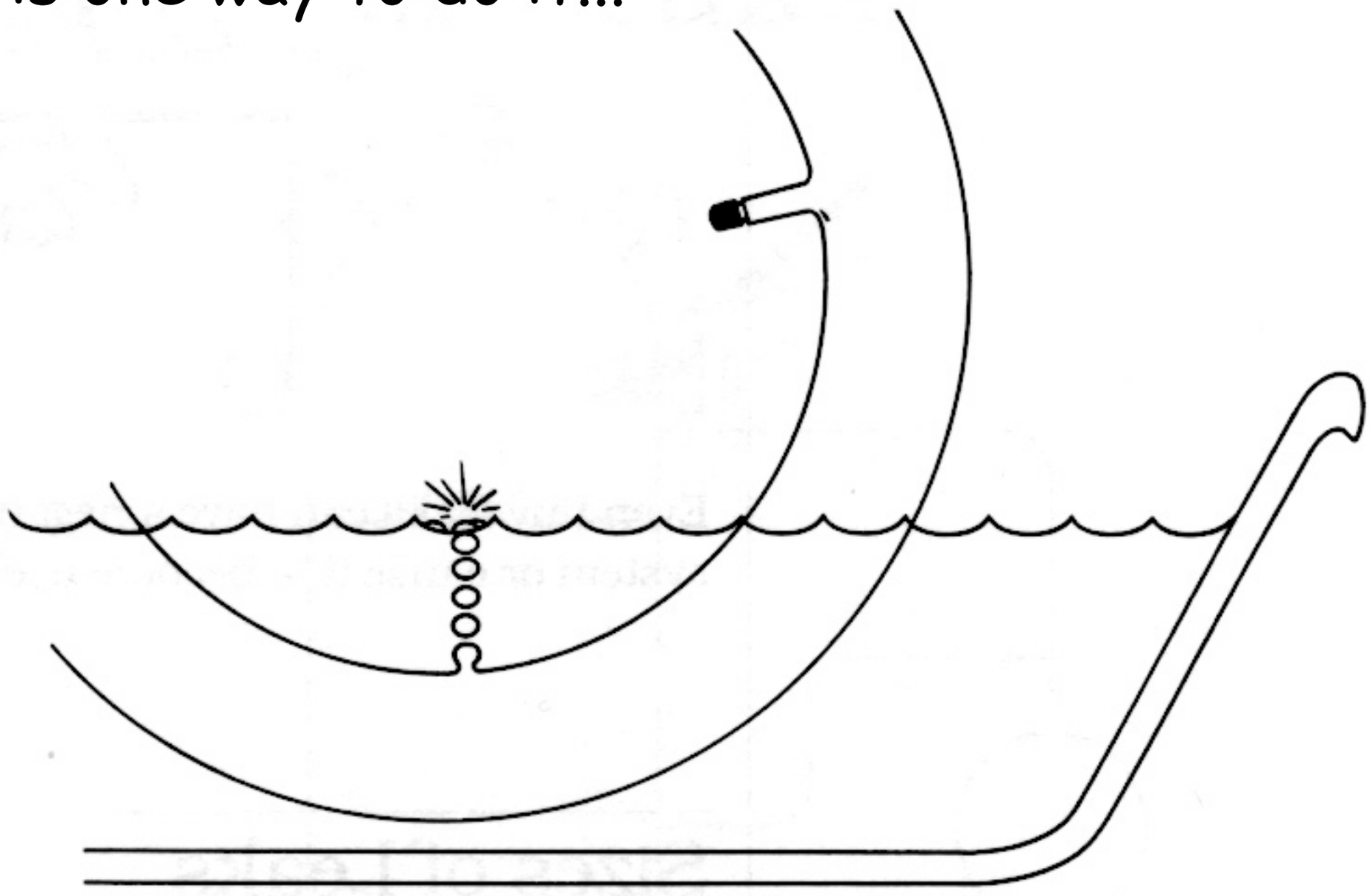




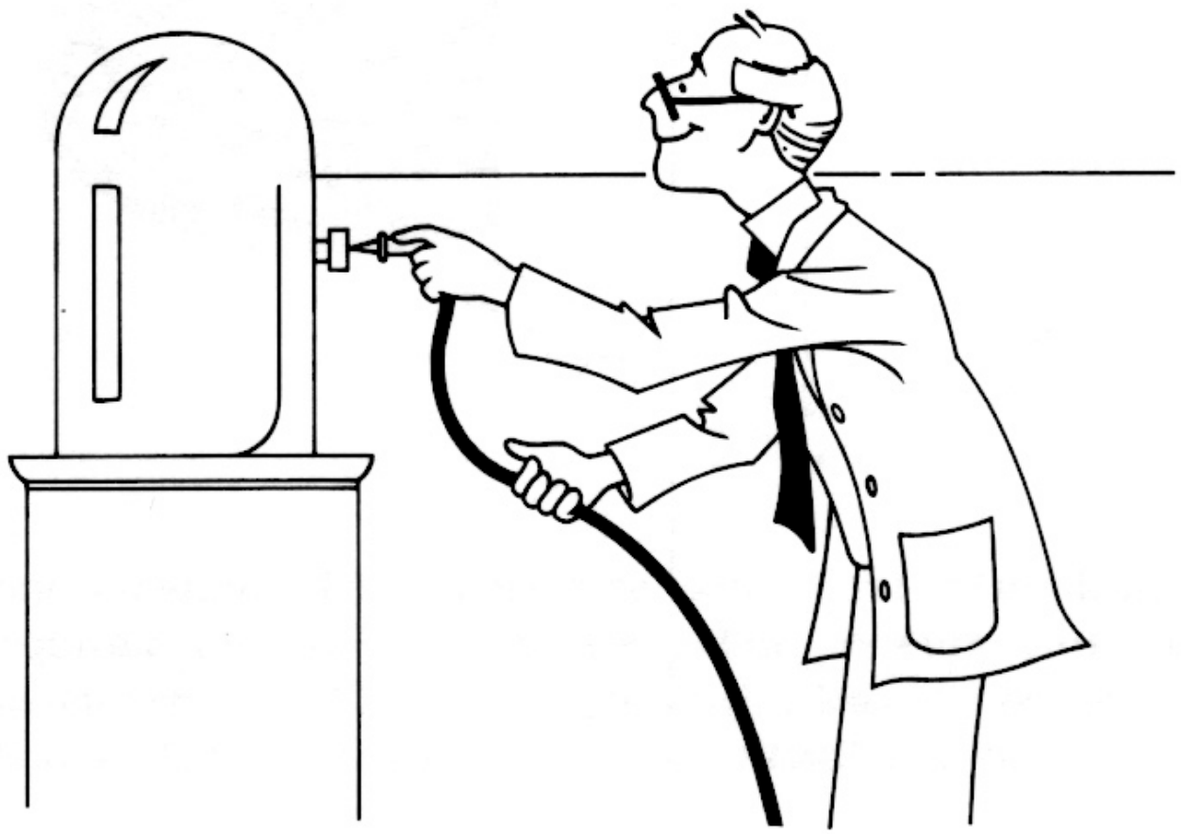
Small leak visible after bake …

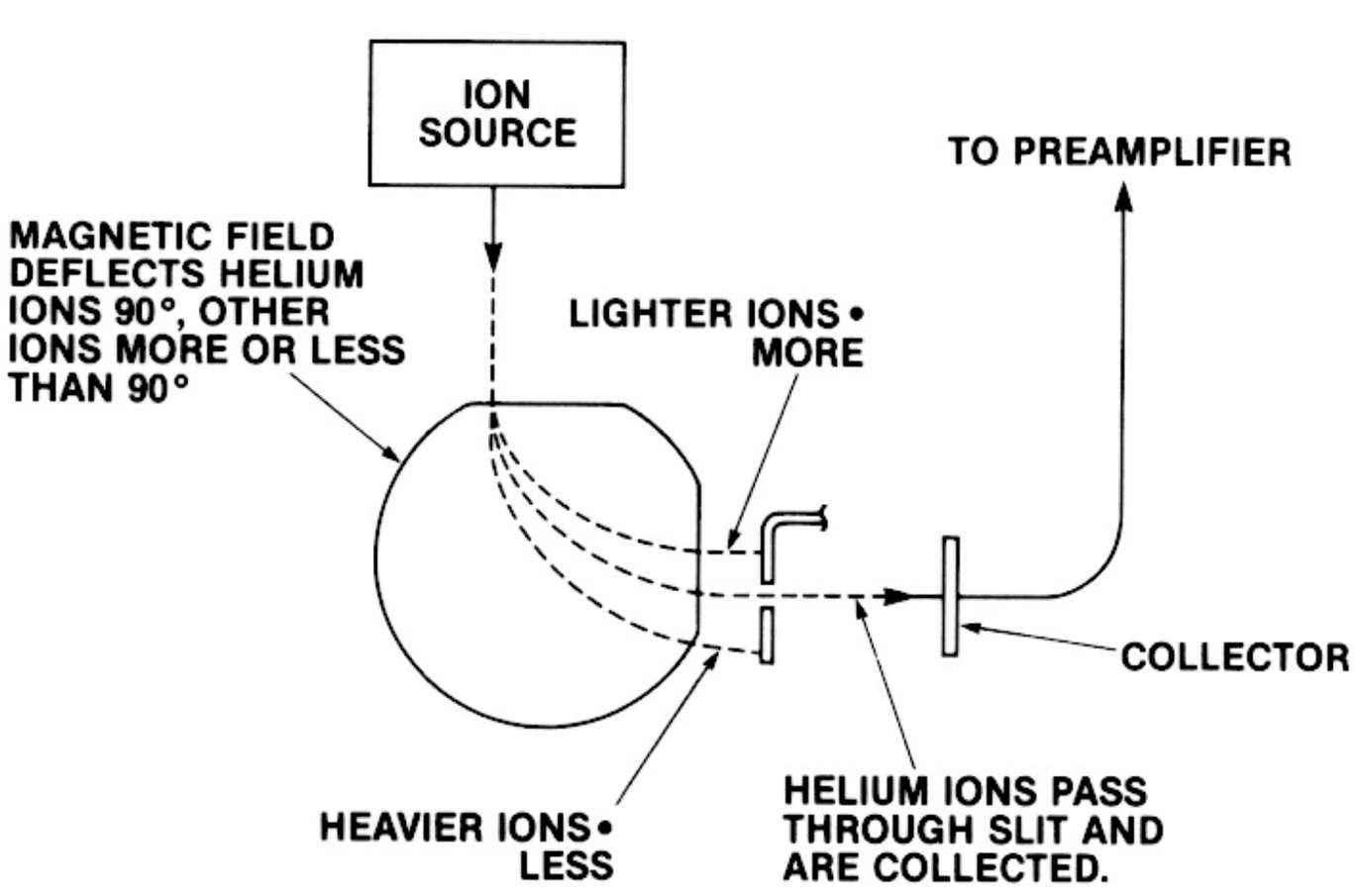


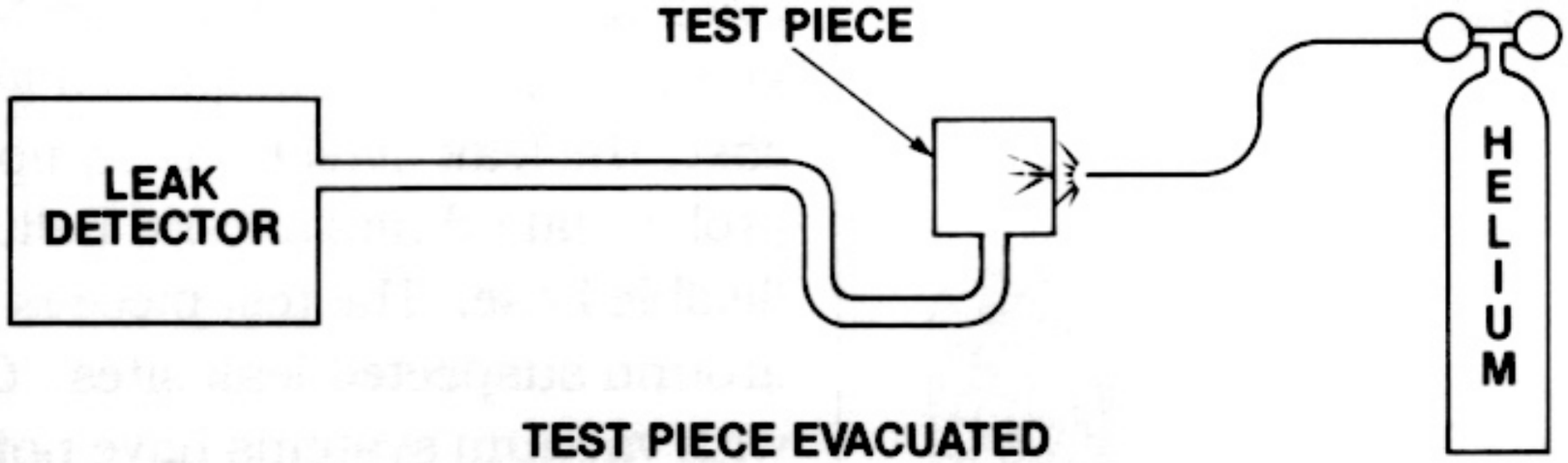
This is one way to do it...



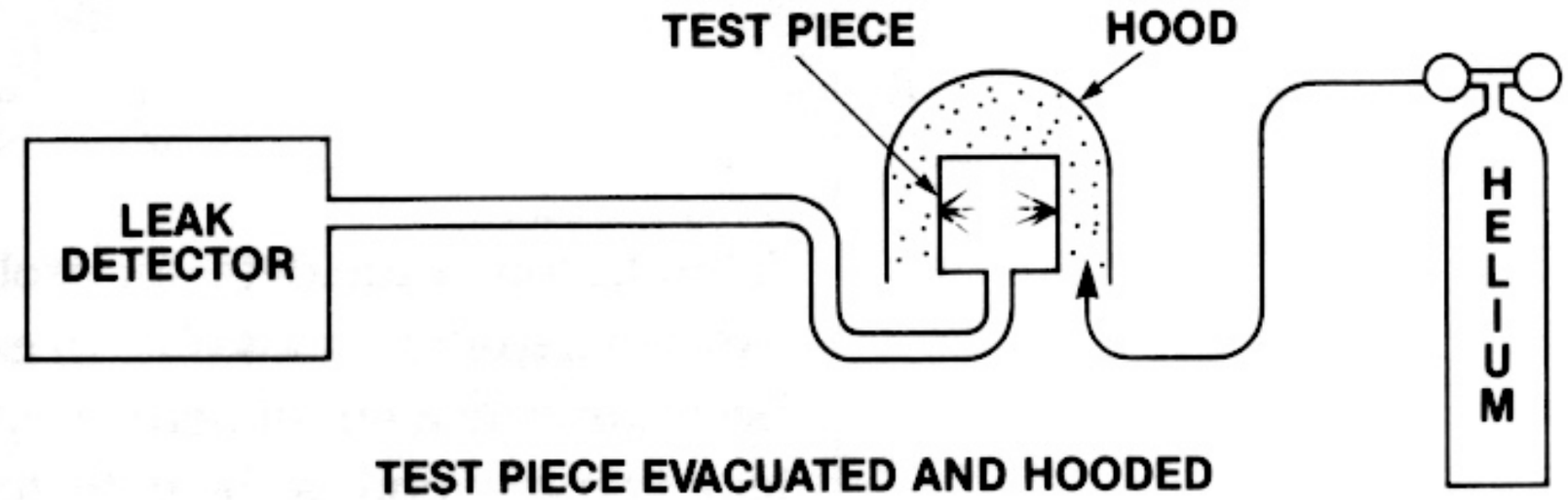
This is another ....



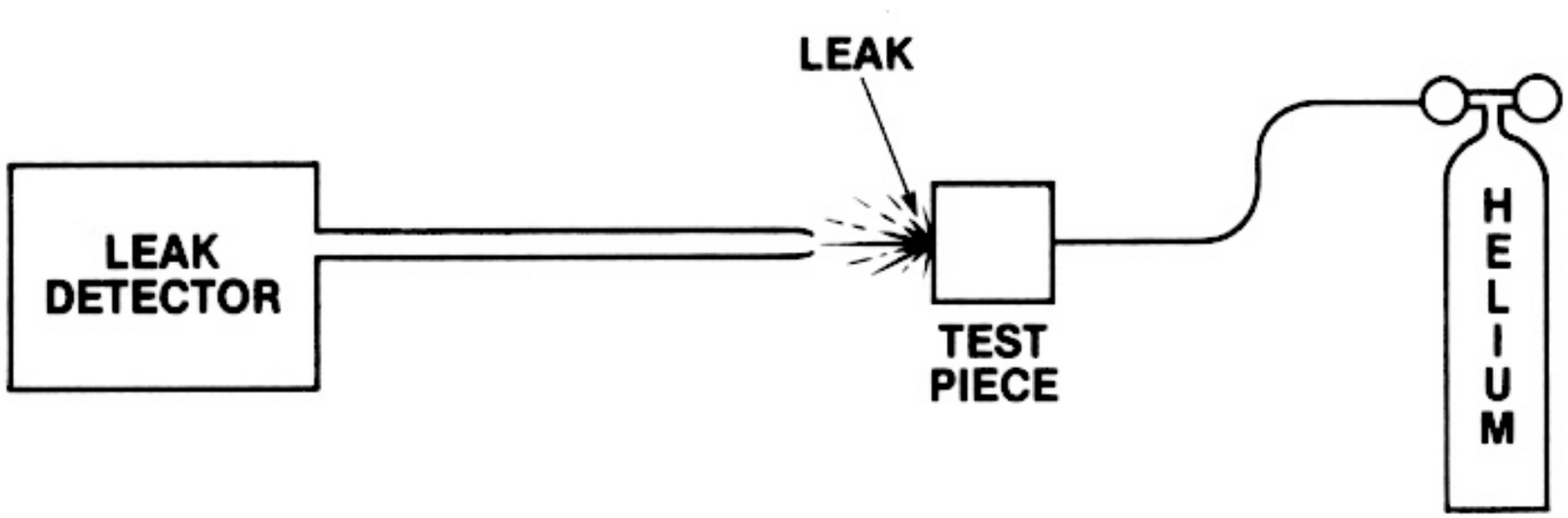




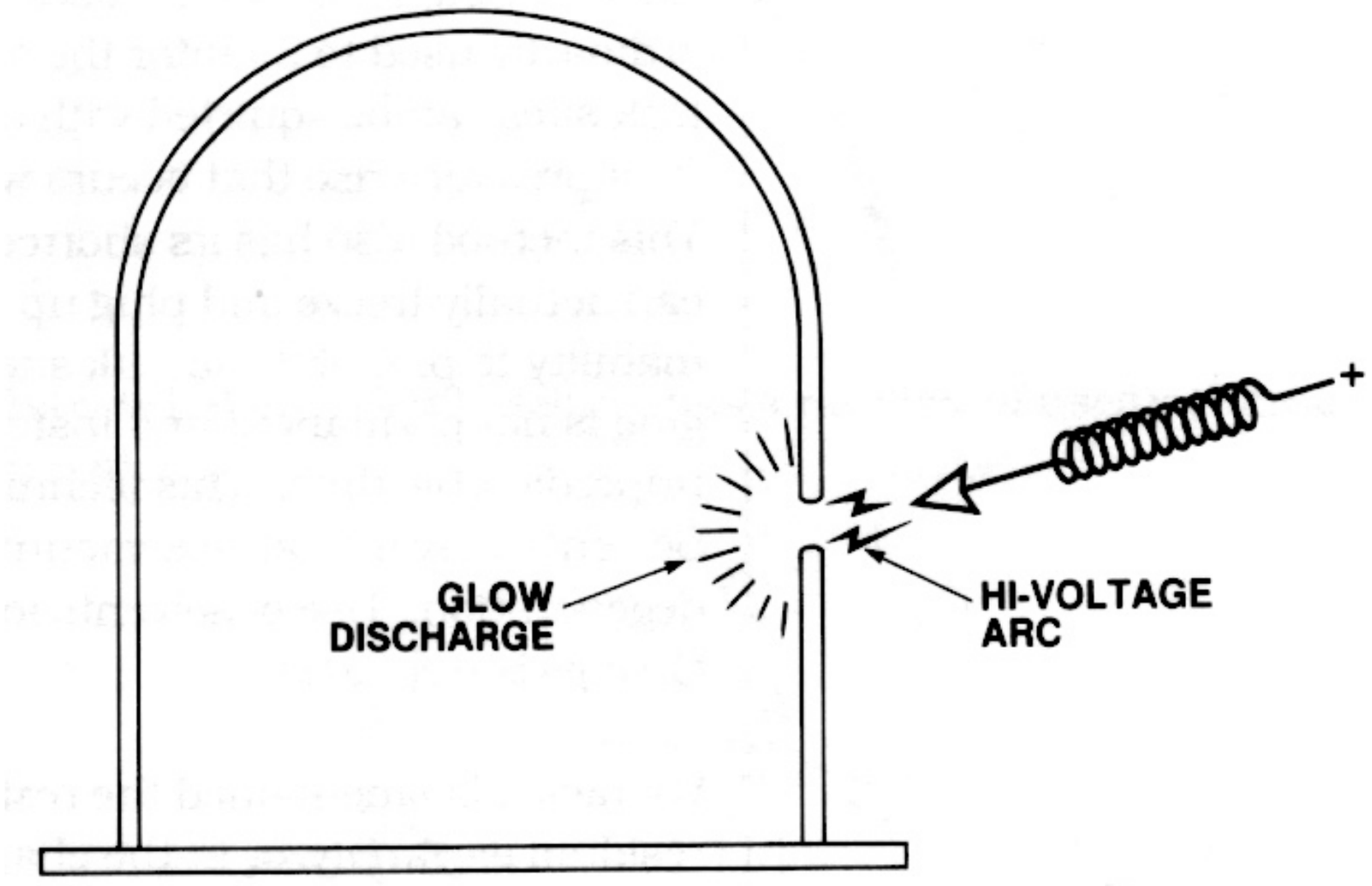
TEST PIECE EVACUATED



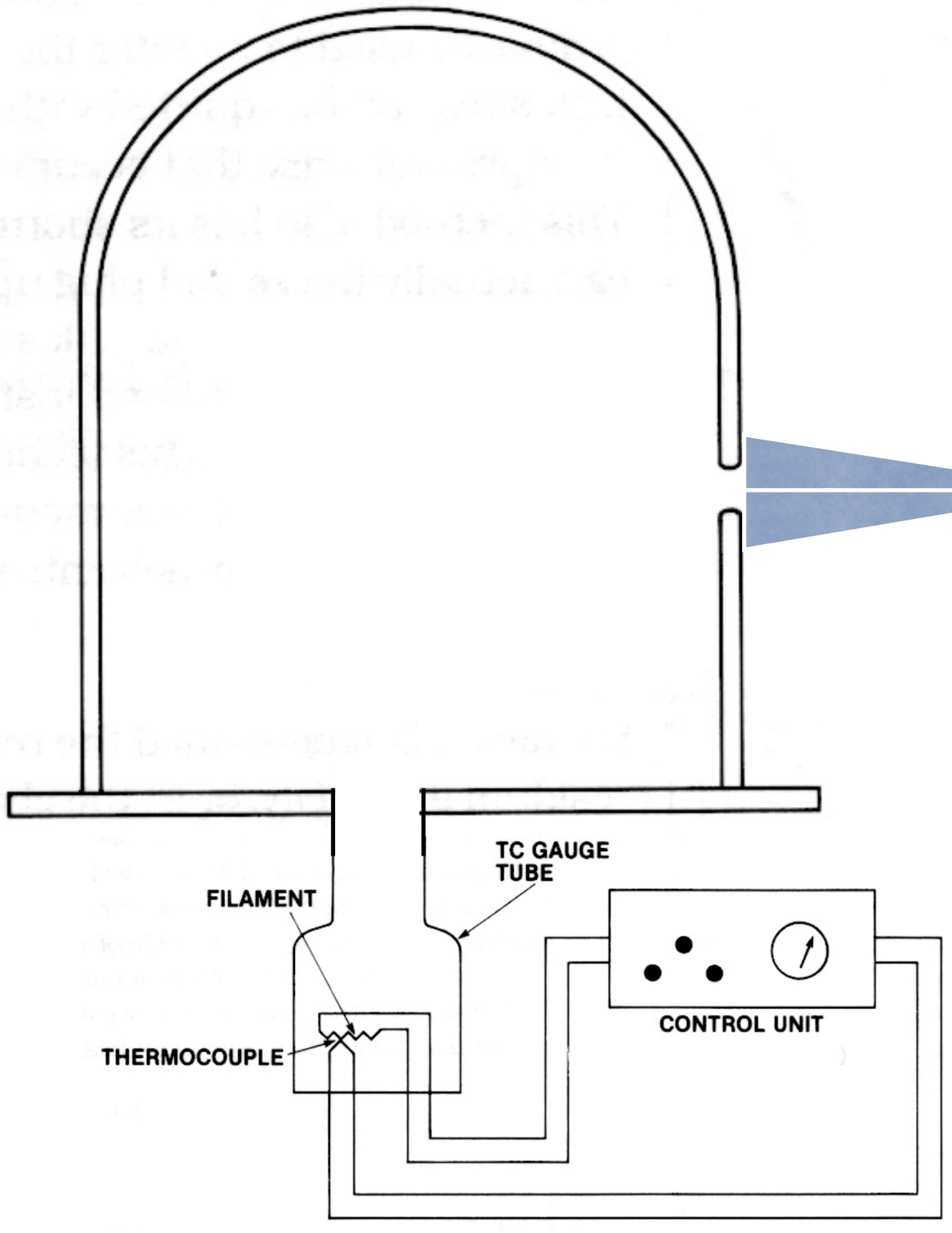
TEST PIECE EVACUATED AND HOODED

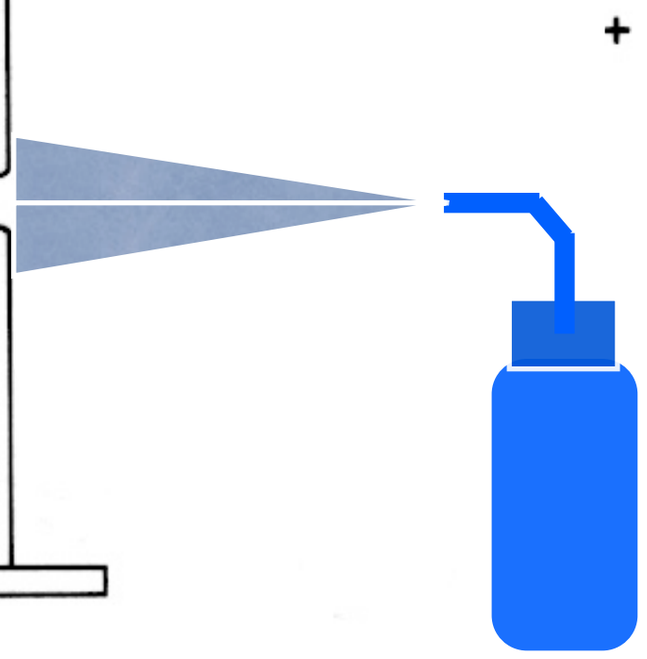


Discharge method



Wet method





Ethanol

Outgassing

always occurs, unless whole system T<~15K

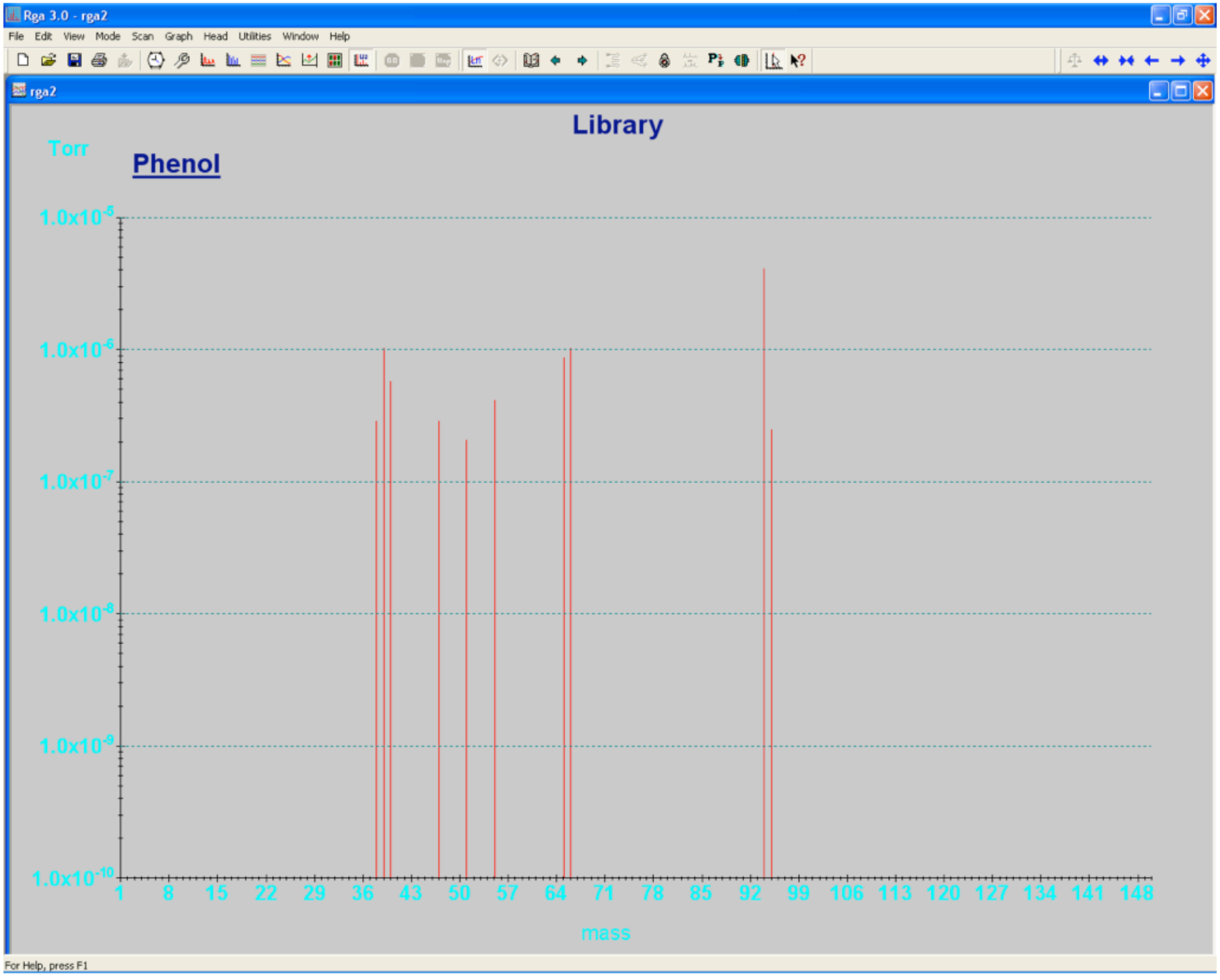
depends strongly on materials inside system

depends on inside surface treatment

increases minimum achievable pressure

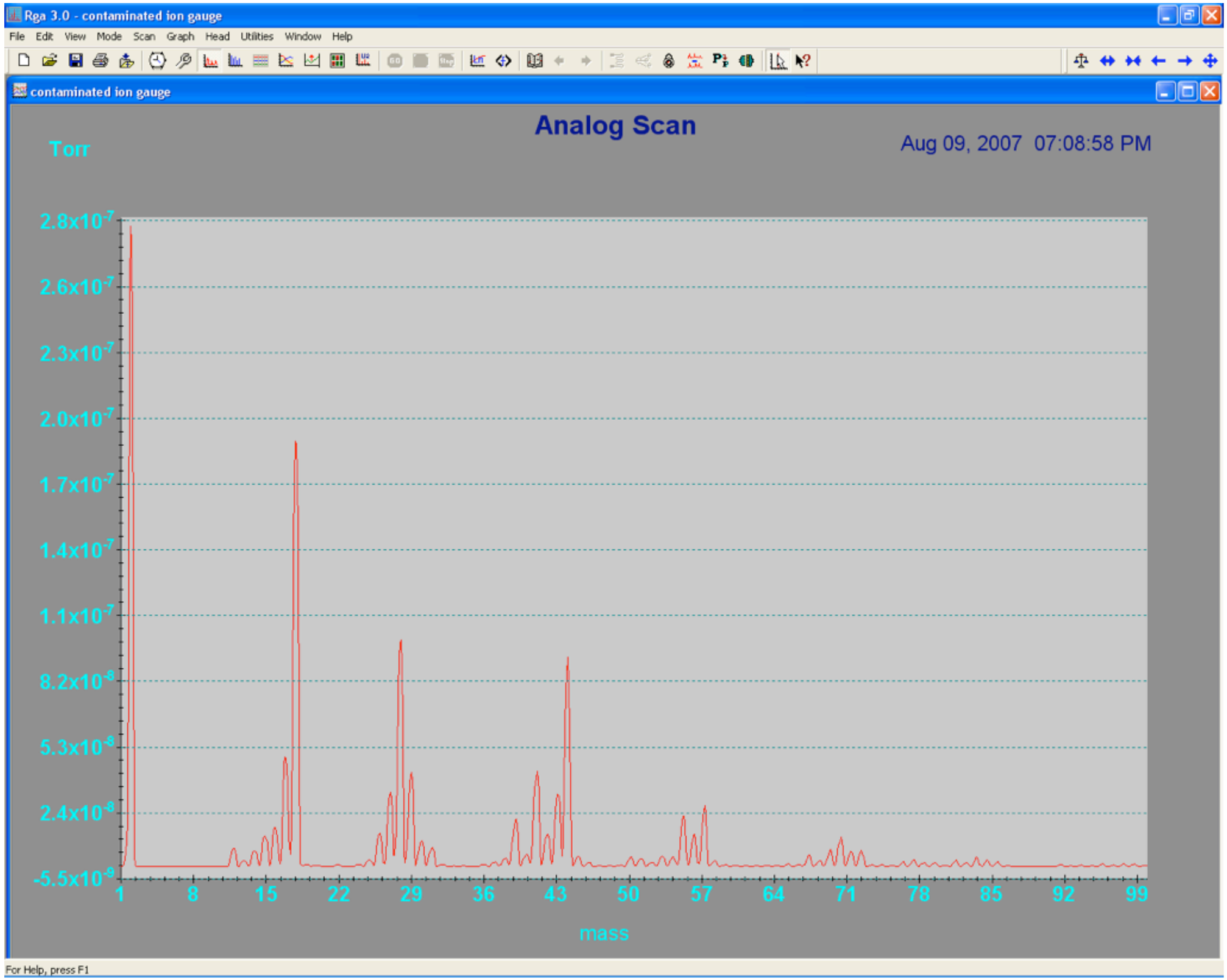
can be remedied by baking

always keep vacuum parts clean (use CLEAN gloves and tools when touching vacuum parts)



gloved bottom scratchers can be detected....

degassing from contaminated gauge tube (sandpaper was used after welding)



VAPOR PRESSURES OF SOME ELEMENTS AT VARIOUS TEMPERATURES

Element	Ref.	Vapor Pressure (mm Hg)						mp (°C)
		10^{-5} at °C	10^{-4} at °C	10^{-3} at °C	10^{-2} at °C	10^{-1} at °C	1 at °C	
Aluminum	1	882	972	1082	1207	1347	1547	659
Antimony	1	382	427	477	542	617	757	630
Barium	1	417	467	537	617	727	867	710
Beryllium	1	902	987	1092	1212	1367	1567	1283
Bismuth	1	450	508	578	661	762	892	271
Cadmium	1	149	182	221	267	321	392	321
Calcium	1	402	452	517	592	687	817	850
Carbon	1	1977	2107	2247	2427	2627	2867	—
Cesium	1	46	75	110	152	206	277	30
Chromium	1	1062	1162	1267	1392	1557	1737	1903
Cobalt	1	1162	1262	1377	1517	1697	1907	1495
Copper	1	942	1032	1142	1272	1427	1622	1084
Gold	1	987	1082	1197	1332	1507	1707	1063
Indium	1	670	747	837	947	1077	1242	156
Iridium	1	1797	1947	2107	2307	2527	2827	2454
Iron	1	1107	1207	1322	1467	1637	1847	1539
Lead	1	487	551	627	719	832	977	328
Lithium	1	348	399	460	534	623	737	181
Magnesium	1	287	330	382	442	517	612	650

Element	Ref.	Vapor Pressure (mm Hg) 10^{-5} at °C	10^{-4} at °C	10^{-3} at °C	10^{-2} at °C	10^{-1} at °C	1 at °C	mp (°C)
Magnesium	1	287	330	382	442	517	612	650
Manganese	1	697	767	852	947	1067	1227	1244
Mercury	1	−28	−8	16	45	81	125	−39
Molybdenum	1	1987	2167	2377	2627	2927	3297	2577
Nickel	1	1142	1247	1357	1497	1667	1877	1452
Osmium	2	2101	2264	2451	2667	2920	3221	2697
Palladium	1	1157	1262	1387	1547	1727	1967	1550
Platinum	1	1602	1742	1907	2077	2317	2587	1770
Potassium	1	91	123	162	208	266	341	64
Rubidium	1	64	95	133	176	228	300	39
Silicon	1	1177	1282	1357	1547	1717	1927	1415
Silver	1	757	832	922	1032	1167	1337	961
Sodium	1	158	195	238	290	355	437	98
Strontium	1	342	394	456	531	623	742	770
Tantalum	1	2397	2587	2807	3067	3372	3737	2997
Thorium	2	1686	1831	1999	2196	2431	2715	1827
Tin	1	882	977	1092	1227	1397	1612	232
Tungsten	1	2547	2757	3007	3297	3647	—	3377
Uranium	1	1442	1582	1737	1927	2157	2447	1130
Zinc	1	208	246	290	342	405	485	420
Zirconium	1	1837	2002	2187	2397	2647	2977	1852

Bakeout

temporary increasing temperature of the system to desorb gases from the walls

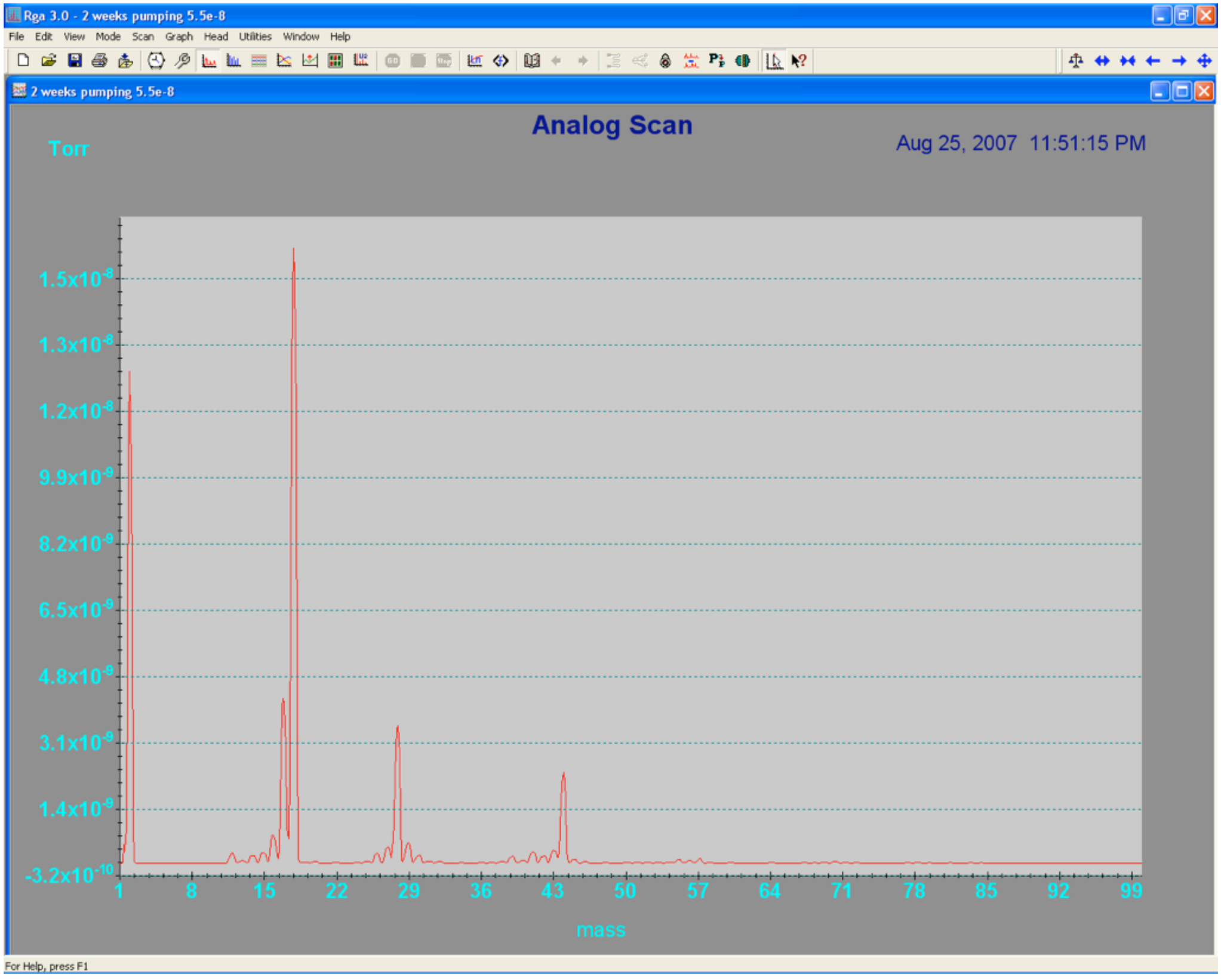
necessary to achieve pressures lower than 10^{-9} Tr the hotter the better (120-250 deg. C)

not to exceed max allowed temperature for components

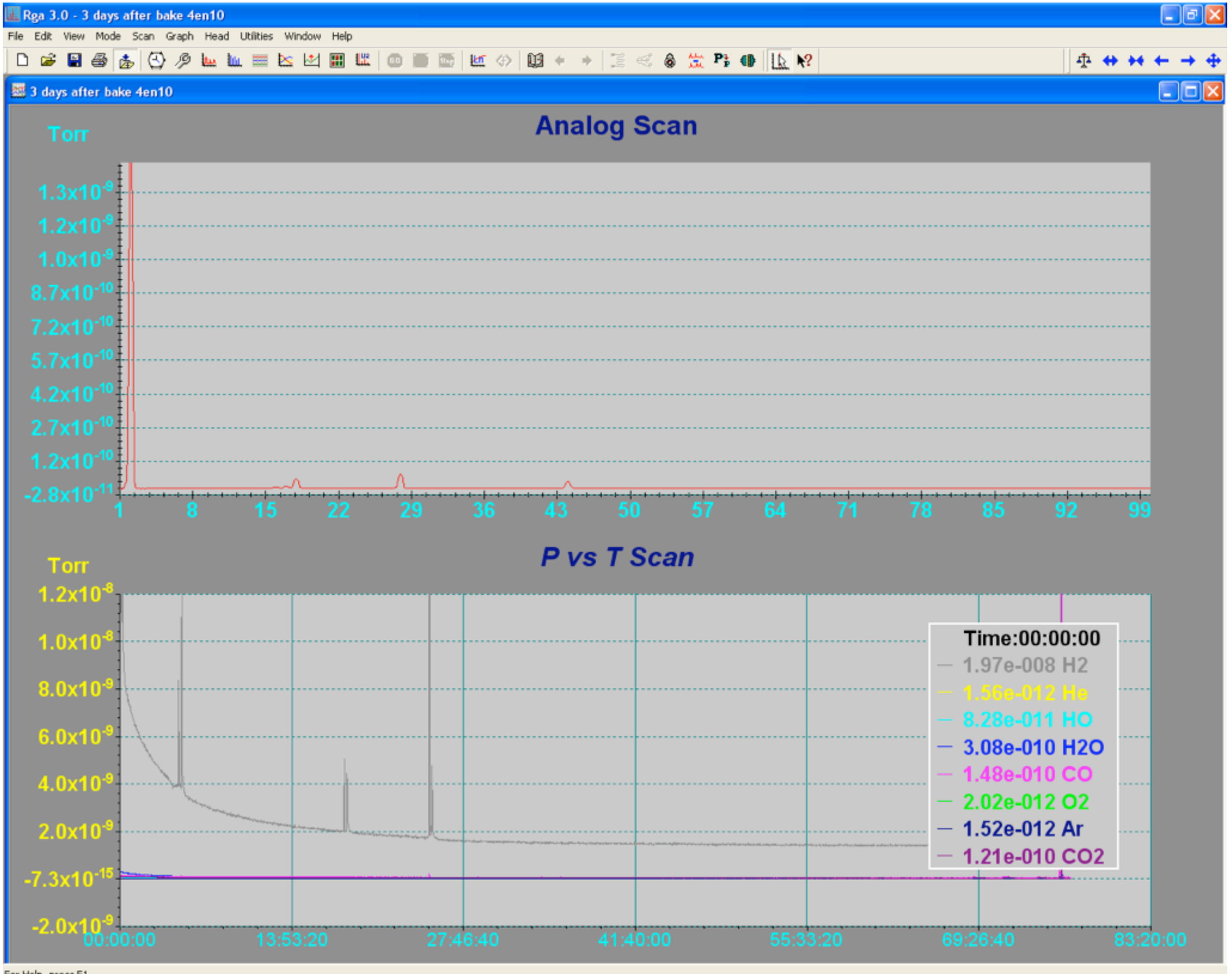
temperature should be as uniform as possible

filament devices should be degassed

2 weeks of pumping after vent



cooldown after the bake



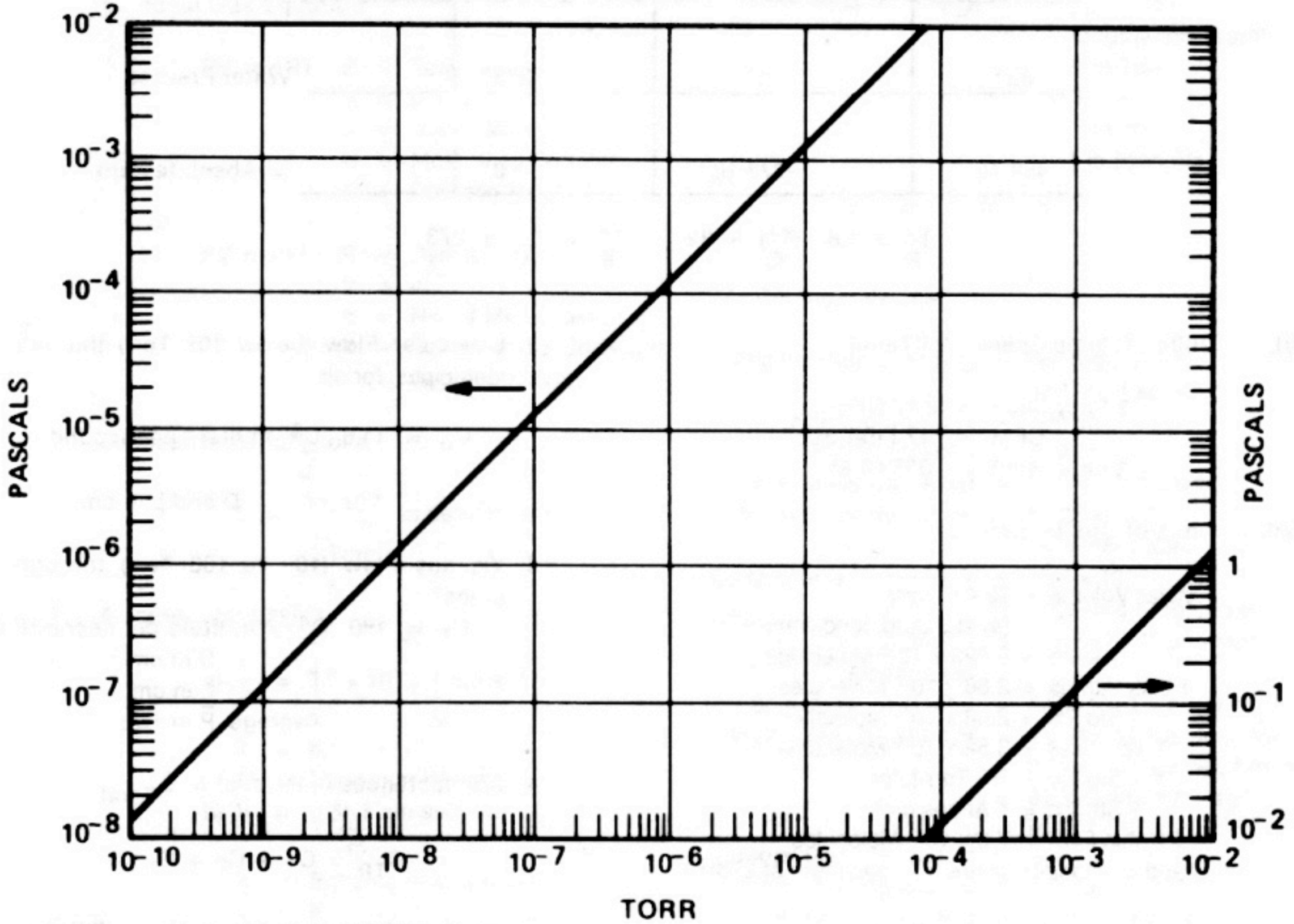
after bake and conditioning

UNITS

	Pascal (N/m^2) (Pa)	Torr	Standard Atmosphere (atm)	Millibar (mbar)	Dyne per Square Centimeter (dyn/cm^2)
1 Newton per square meter (N/m^2) = Pascal =	1	7.5 x 10^{-3}	9.87 x 10^{-6}	10^{-2}	10
1 Torr = 1mm Hg =	133	1	1.32 x 10^{-3}	1.33	1,330
1 standard atmosphere (atm) =	101,000	760	1	1,010	1,010,000
1 millibar (mbar) =	100	0.75	9.87 x 10^{-4}	1	1,000
1 dyne/square centimeter (dyn/cm^2) =	10^{-1}	7.5 x 10^{-4}	9.87 x 10^{-7}	10^{-3}	1

UNITS OF PRESSURE

Prepared by
American Vacuum Society Standards Committee



VACUUM DIMENSIONS AND FORMULAS

I. Units of Length

1 Meter = 100 Centimeters (cm)
1 cm = 10 Millimeters (mm)
1 mm = 1000 Microns (μ)
1 μ = 10^{-3} mm
1 μ = 10^{-6} Meter
1 Liter = 10^{3} cm^{3}
1 Inch = 2.54 cm
1 Ft^{3} = 1728 in^{3} = 28316.8 cm^{3}
1 Ft^{3} = 28.3 Liters
1 Mile = 160,934 cm
= 63,360 in
= 5,280 ft

II. Units of Mass

1 Pound = 453.5 Grams (g)
Density of Mercury = 13.546 g cm^{-3}
Density of Water = 1 g cm^{-3}

III. Units of Force

1 Dyne = Force Required to Accelerate 1 g, 1 cm sec^{-2}
1 Gram = 980.6 Dynes (Gravity, Sea Level, 45° Lat)
1 Newton = Force Required to Accelerate 1 Kg, 1 Meter Sec^{-2}
1 Newton = 1 x 10^{5} Dynes
1 Pound = 4.45 x 10^{5} Dynes
1 Pound = 4.45 Newtons

IV. Units of Pressure (Force/Area)

1 Atmosphere = 1.013 x 10^{6} Dynes cm^{-2}
1 Atmosphere = 14.69 lbs. in^{-2}
1 Atmosphere = 1030 Grams cm^{-2}
1 Atmosphere = Column of Hg. 76 cm High
1 Atmosphere = Column of Hg. 29.9 Inches High
1 Torr = 1/760 Atmosphere
1 Torr = Column of Hg. 1 mm High
1 Torr = 1.33 x 10^{3} Dynes cm^{-2}
1 Micron = 10^{-3} Torr = 1.33 Dynes cm^{-2}
1 Bar = 10^{6} Dynes cm^{-2} (English)
1 Bar = 750 Torr
1 Millibar = .75 Torr
1 Microbar = 7.5 x 10^{-4} Torr
1 Barye = 1 Microbar = .9975 Dynes cm^{-2}
1 Micron = 1.01 Dynes cm^{-2}
1 Pascal = 1 Newton $Meter^{-2}$
1 Pascal = 7.5 Microns
1 Torr = 133.3 Pascals
1 lb. in^{-2} = 2.036 Inches Hg = 5.17 cm Hg (0 °C, 45 ° Lat)

1 in = 2.54 cm = 25.4 mm

1 ft = 12 in

1 international mile = 5,280 feet=1,609.344 m

1 US survey mile = 5,280 feet=1,609.347219 m

1 nautical mile = 6,076 feet=1,852.00 m

VOLUME

from/to	cm^3	liter	in^3	ft^3	fl oz	pt.	qt.	gal.
cm^3	1	.001	0.06102	3.53×10^{-5}	.03381	.00211	.00106	2.64×10^{-4}
liter	1000	1	61.02	0.03532	33.81	2.113	1.057	.2642
in^3	16.39	0.01639	1	5.79×10^{-4}	.5541	.03463	0.01732	.00433
ft^3	2.83×10^4	28.32	1728	1	957.5	59.84	29.92	7.481
fl oz	29.57	0.02957	1.805	0.00104	1	.06250	.03125	.00781
pt	473.2	0.4732	28.88	0.01671	16	1	0.500	0.1250
qt	946.4	0.9463	57.75	0.03342	32	2	1	0.2500
gal (US)	3785	3.785	231	0.1337	128	8	4	1

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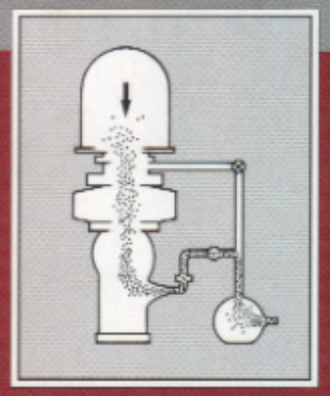

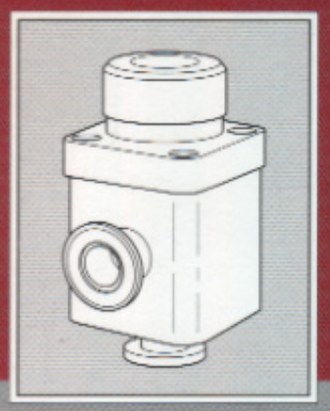

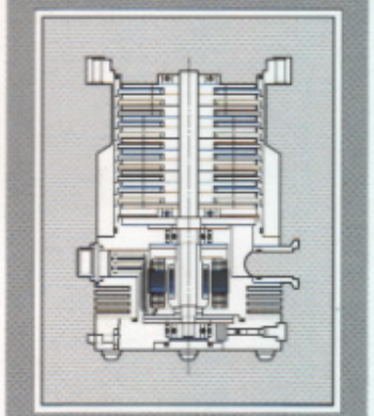

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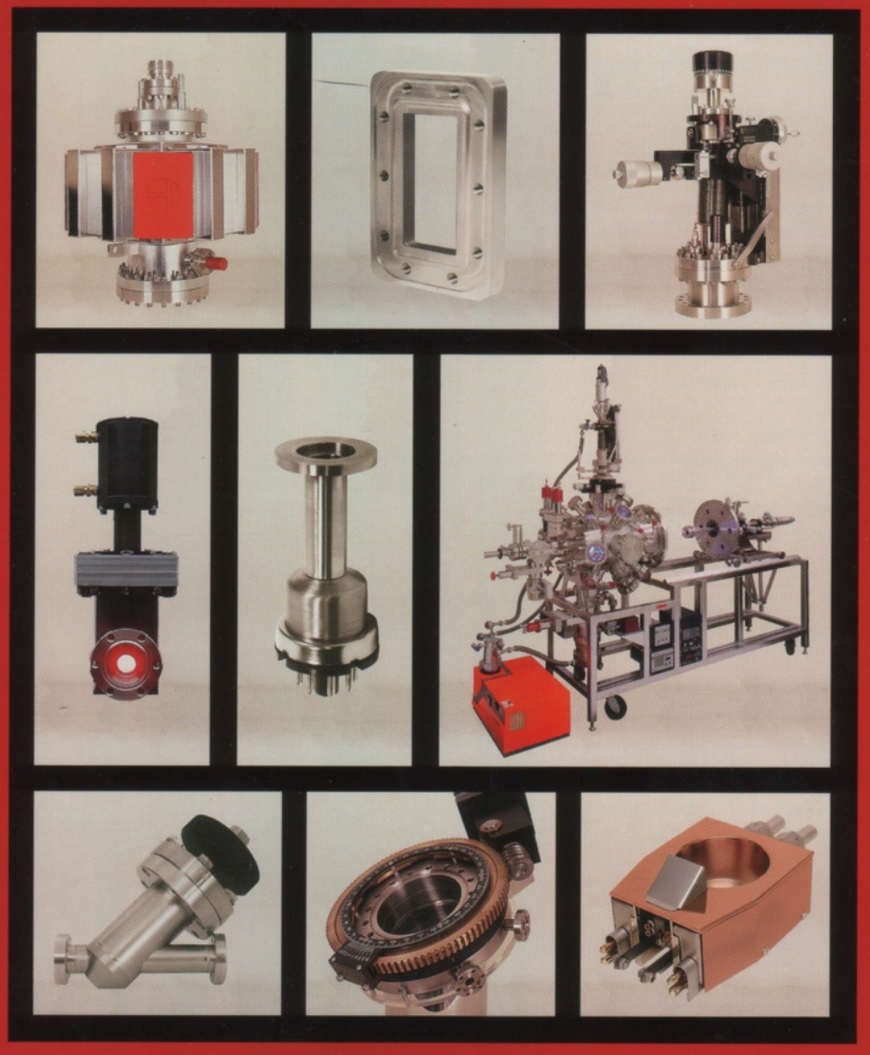

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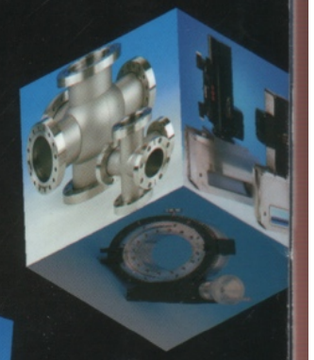

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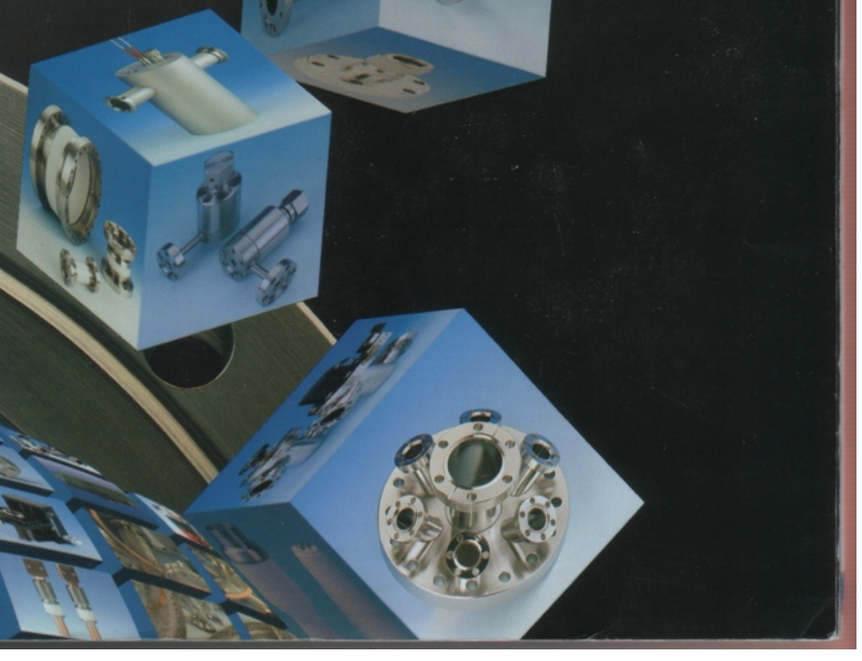

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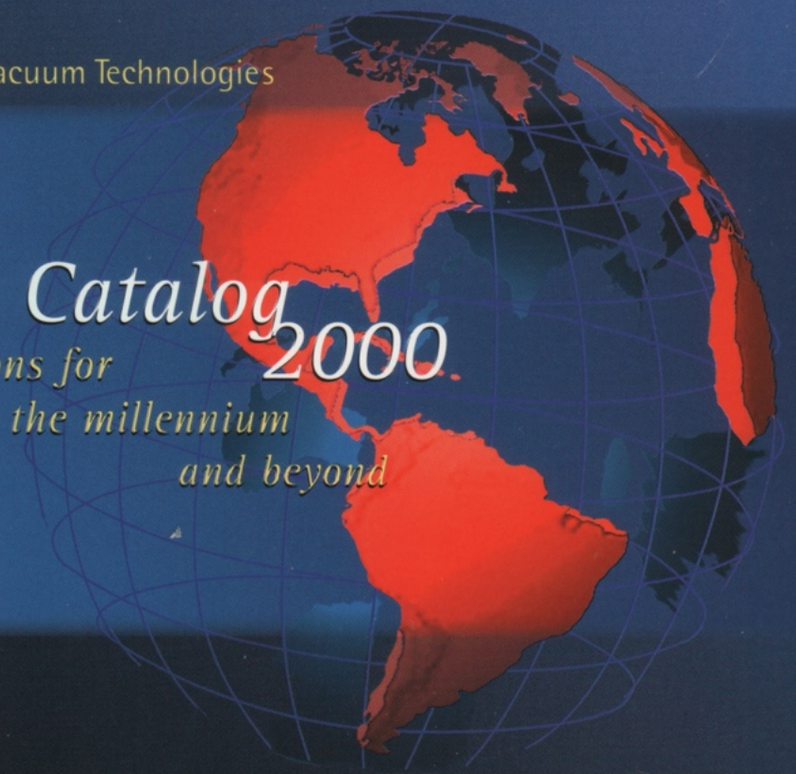

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